City of Cambridge Water Department 2018 Source Water Quality Report

Hobbs Brook Reservoir Gatehouse, October 30, 2018

February 2020

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1 EXECUTIVE SUMMARY

This report presents the 2018 results of the City of Cambridge Water Department (CWD)'s Source Water Quality Monitoring Program, an ongoing study to assess source water quality in Cambridge reservoirs and associated tributaries. This report is intended to aid City managers and decision makers and to educate those who are interested in the Cambridge water supply.

In 2018, CWD conducted water quality sampling year-round in the City's three reservoirs: Hobbs Brook Reservoir, Stony Brook Reservoir, and Fresh Pond Reservoir. Additionally, water quality data were collected from 12 streams feeding the reservoirs during base-flow conditions. The U.S. Geological Survey (USGS) also collected water quality data at nine tributary sites and the reservoirs, including stormwater sampling at four tributary stations. Calendar year 2018 water quality monitoring results were compared against state and federal ambient and drinking water quality standards and guidelines. Results were also compared against historical data collected by CWD since 2000 and by the USGS during a 1997-1998 baseline assessment.

The Class A Massachusetts Surface Water Quality Standards (Class A standards) are set to protect designated uses, such as aquatic life, primary contact recreation, and aesthetic value. Based on the parameters analyzed by CWD such as pH, temperature, dissolved oxygen (DO), chloride, *E. coli* bacteria, and eutrophication indicators, the surface water quality in Cambridge's three reservoirs and 12 tributary monitoring sites was generally found to be protective of aquatic life, safe for primary contact, and provided pleasing aesthetics. However, there were a few notable exceptions.

First, chloride impairment was a widespread issue in the Cambridge watershed. One hundred percent of samples collected from the Hobbs Brook Reservoir lower basin in 2018 exceeded the 230 mg/L chronic toxicity standard set to protect aquatic life. In fact, chloride concentrations at Hobbs Brook Reservoir were high enough that 86 percent of the weekly samples also exceeded the 250 mg/L Secondary Maximum Contaminant Level (SMCL), an aesthetic threshold above which drinking water can taste salty. The upper and middle basin of Hobbs Brook Reservoir were less chloride impaired, with no shoreline samples from the upper basin exceeding 230 mg/L in 2018 and only half of samples exceeding 230 mg/L in the middle basin.

Because the three reservoirs are located in succession, elevated chloride concentrations in the Hobbs Brook Reservoir lower basin impacted water quality downstream at Stony Brook Reservoir, causing exceedances of the 230 mg/L during the Hobbs Brook Reservoir summer water release period. Only one sample at Fresh Pond exceeded 230 mg/L in 2018 and the result may have been inaccurately high. No samples at Fresh Pond, the terminal reservoir in the Cambridge surface water supply system, exceeded the 250 mg/L SMCL. The primary source of chloride in Hobbs Brook Reservoir is deicing chemicals applied to nearby roadways and parking areas, such as I-95, which borders the reservoir.

The tributary sites located in catchments with high percentages of impervious cover and roadway miles also had the highest concentrations of chloride. Impervious cover in the 12 tributary catchments monitored by CWD ranged from 5.9 percent to 64.7 percent and the miles of road per square mile of catchment area ranged from 6.4 mi/mi^2 to 24.8 mi/mi^2. One exception was the Salt Depot catchment, where elevated chloride levels were largely attributable to a historic groundwater salt plume from improperly stored highway salt. Seven of 12 tributary sites had median chloride base-flow concentrations above 230 mg/L EPA in 2018 while one site, Indust Brook, had a median base-flow concentration above the 860 mg/L acute toxicity standard for aquatic life. This site has one of the smallest catchment areas, minimizing the impact to the overall load of chloride entering the Stony Brook Reservoir.

Chloride concentrations in all three reservoirs and most tributaries demonstrated an increasing trend starting in 2012 and appeared to level off between 2016 and 2018. This period had below normal precipitation, including a drought that lasted from October 2016 through April 2017. Prior to this period, exceedances of the 230 mg/L chronic toxicity standard were rare in the Cambridge reservoirs. A comparison of base-flow and stormflow concentrations at four tributary sites in 2018 showed that base-flow salt concentrations were higher than stormflow concentrations. Therefore, it was unsurprising that reservoir chloride concentrations increased during dry periods when recharge would be dominated by groundwater.

Above normal precipitation in 2018 appeared to help reduce reservoir chloride concentrations and above normal precipitation in 2019 will hopefully allow reservoir chloride concentrations to continue trending downward. Interestingly, from a volumetric perspective, the Hobbs Brook Reservoir had recovered from the drought in 2018. However, the lingering effects of the elevated chloride concentrations remained. This indicates that CWD may need to manage the reservoirs for chemical impacts, in addition to volumetric impacts, in future droughts.

Sodium trends in the reservoirs and tributaries mirrored chloride, an unsurprising pattern since sodium chloride is a common road deicing chemical used in the Cambridge watershed. Although elevated sodium is not regulated for impacts to aquatic life, awareness of sodium concentrations is important for human individuals monitoring sodium intake for health purposes. The Massachusetts Drinking Water Guidelines for treated drinking water is 20 mg/L; sodium concentrations in the Cambridge watershed reservoirs and tributaries have consistently exceeded this guideline since at least 2000. At Fresh Pond Reservoir, the median sodium concentration was 118 mg/L in 2018. However, drinking water is typically not a major source of sodium in human diets.

In a typical year, temperature, pH, and DO levels from surface readings at all three reservoirs remain within the Class A bounds set to protect aquatic life in warm water fisheries. However, minor excursions above the temperature Class A standard (28.3 degrees C) were measured by CWD and/or the USGS in all three reservoirs in 2018. CWD also measured pH levels ranging from 8.69 to 8.98 at Stony Brook Reservoir during a two-week period in August. According to Massachusetts Department of Environmental Protection guidance, pH levels more than 0.5 standard units above 8.3 represent an extreme exceedance and have the potential to harm aquatic life.

The temperature and pH excursions in 2018 usually occurred during periods with air temperatures above 90 degrees F. Warmer than normal air temperatures, particularly consecutive days above 90 degrees F in August, likely caused the elevated water temperatures. The warm water temperatures may have helped increase algal productivity resulting in the elevated pH at Stony Brook Reservoir. Although pH and temperature levels in Cambridge reservoirs are typically protective of wildlife, 2018 showed how reservoir water quality could be vulnerable to an increased number of high heat events caused by climate change.

DO in the Hobbs Brook, Stony Brook, and Fresh Pond epilimnions remained above the 5 mg/L warm water fishery Class A standard during 2018, consistent with prior years. All three reservoirs were thermally stratified from the June through September, although the stratification was less severe at Fresh Pond

Reservoir, where an aeration system supplied oxygen to help the reservoir mix and prevent oxygen depletion in the lower depths. At Hobbs Brook and Stony Brook Reservoirs, DO dropped below 5 mg/L at 4 to 6 meters in depth. The deepest point in both reservoirs was approximately 9 meters. The portion of the water column with DO below 5 mg/L was less extensive at Fresh Pond Reservoir, beginning at 9 to 14 meters in depth. Fresh Pond Reservoir is Cambridge's deepest reservoir, with a maximum depth of approximately 15 meters.

Despite being an impoundment, Stony Brook Reservoir is classified by the Massachusetts Division of Fisheries and Wildlife as a coldwater fish resource (CFR). Therefore, temperature and DO concentrations at Stony Brook Reservoir were also compared against the 20 degree C seven-day average daily maximum (7-DADM) temperature and 6 mg/L DO Class A standards. Continuous data were not available to calculate the 7-DADM at Stony Brook Reservoir, although discrete surface water temperatures exceeded 20 degrees C in the June through August profiles in 2018, a result in line with past years. Comparing DO concentrations in the hypolimnion against the 6 mg/L CFR standard instead of the 5 mg/L warm water fish resource standard expanded the zone of low DO by approximately one meter.

In 2018, tributary water quality was also generally supportive of aquatic life when evaluated against the Class A temperature, DO, and pH standards for warm water fisheries. For example, all discrete temperature measurements in 2018 were cooler than 28.3 degrees. While USGS continuous temperature data from the Lex Brook, Tracer Ln, and WA-17 tributary sites exceeded 28.3 degrees C during periods when air temperatures approached or exceeded 90 degrees F, no site exceeded the Class A standard frequently enough to be considered detrimental to aquatic life. However, tributaries and their supported aquatic life appear to be vulnerable to increased high heat days due to climate change.

Tributary DO concentrations remained above 5 mg/L at all 10 warm water tributary stations, except during the summer months at the at HB @ Mill St, Tracer Ln, and MBS sites. Similarly, excursions of pH below the 6.5 Class A minimum were also observed at HB @ Mill St and Tracer Ln during the summer, presumably the result of carbon dioxide production during microbial respiration. All three sites were downstream of highly organic wetlands. MBS and Tracer Ln have historically experienced low summer DO and occasionally low pH. Low DO and pH during the summer is rarer at HB @ Mill St, but a beaver dam observed upstream of the monitoring station in June of 2018 resulted in lower flows and a build-up of organic matter at the monitoring station. Due to these factors, more instances of low DO and pH are expected at HB @ Mill St in the future.

CWD also monitored two CFR tributary sites along the Stony Brook river: SB @ Viles and RT 20. Both sites regularly exceed the 7-DADM of 20 degrees C during the summer months, although the exceedance period is typically longer in duration at RT 20 than at SB @ Viles. This pattern held true in 2018. RT 20 is downstream of SB @ Viles and is impacted by releases of water from Hobbs Brook Reservoir, whereas SB @ Viles is not impacted by releases from the reservoir. This suggests that land use patterns in the watersheds were likely more responsible for the elevated water temperatures than releases of water heated in the upstream impoundments. Further supporting this hypothesis, the amount of natural land was too low, and the amount of impervious cover too high, for the temperature exceedances to be considered naturally occurring per Massachusetts Department of Environmental Protection (MA DEP) guidelines. Continuous DO data were not collected, although discrete DO readings in 2018 were above 6 mg/L, suggesting adequate levels of DO for aquatic life.

Cambridge reservoirs were protective of aquatic life with respect to nutrient enrichment, although the reservoirs have likely experienced eutrophication due to human-caused nutrient inputs relative to reference conditions. When compared against the MA DEP nutrient indicator screening guidelines of chlorophyll-*a* (chl-*a*) (<16 mg/m^3), mean summer total phosphorus (TP) concentrations (<0.025 mg/L), and Secchi depth (SD) transparency (>1.2 meters), reservoir water quality was not considered nutrient impaired. Non-rooted macrophyte coverage of the reservoirs was less than the MA DEP indicator guideline of 25 percent coverage, although rooted plant growth was not assessed by CWD and may have been more extensive. The U.S. Environmental Protection Agency's (EPA) nutrient criteria were developed to assess water quality relative to natural conditions. When compared against these criteria, all three reservoirs, as well as the 12 tributaries, had at least one excursion from the nitrogen (nitrate and nitrite, total nitrogen, total Kjeldahl nitrogen), TP, and SD (reservoirs only), and turbidity (tributaries only) criteria in 2018, and in some cases exceeded the EPA nutrient criteria in 100 percent of samples. This suggests at least some eutrophication due to human influences, although the MA DEP nutrient enrichment indicators suggest this is not problematic for reservoir aquatic life.

Of the three reservoirs, Fresh Pond was the least eutrophic both in 2018 and during the 1997-1998 USGS baseline assessment. Fresh Pond was the only reservoir categorized as oligotrophic according to Carlson's Trophic State Index (TSI) during both time periods. The upper basins of Hobbs Brook Reservoir were the most eutrophic in 2018 as well as during the baseline study, with median TSIs in the mesotrophic zone. Similarly, chl-*a* (used to calculate TSI), TP, and turbidity were lowest in Fresh Pond Reservoir and highest in the upper basins of Hobbs Brook while SD transparency was lowest in the Hobbs Brook upper basins and highest at Fresh Pond. Stony Brook Reservoir may have become slightly more eutrophic since the baseline study, although it was unclear if increases in median chl-*a*, TP, and TSI were due to natural variation or worsening water quality. CWD decommissioned an aeration system at Stony Brook Reservoir in 2014, which may explain the change. However, any changes in eutrophication at Stony Brook Reservoir were not replicated downstream at Fresh Pond. All three reservoirs showed increased water clarity when comparing median SD readings between 2018 and the 1997-1998 baseline study, the largest of which occurred at Hobbs Brook Reservoir where median SD transparency increased from 2.2 meters in 1997-1998 to 3.8 meters in 2018.

All three reservoirs are phosphorus limited, meaning that increases in algae growth and productivity are more governed by phosphorus inputs than by nitrogen inputs. Phosphorus tends to sorb to particles which can wash into water bodies during storm events. Therefore, it was unsurprising that TP concentrations were highest in stormflow rather than base-flow samples at the four tributary stations (Lex Brook, Tracer Ln, WA-17, and Summer St) for which both storm and base-flow data were available in 2018. At these four sites, stormflow accounted for between 76 percent and 94 percent of the total load. By contrast, the sodium and chloride loads from these four sites were base-flow dominated, with stormflow accounting for only 28 percent to 38 percent of the salt loads.

In the absence of oxygen, metals such as iron and manganese convert from solid to aqueous form, resulting in increased concentrations in the water column. In addition, phosphorus sorbed to iron particles can be released into the water column. Both iron and manganese can lead to aesthetic issues in treated drinking water while phosphorus can lead to unwanted plant and algal growth in source water. Unsurprisingly, iron and manganese concentrations in 2018 were highest at the bottom of the reservoirs during summer stratification when DO concentrations were lowest, often exceeding the SMCLs of 0.3 mg/L (iron) and 0.05 mg/L (manganese), although the exceedance rate was lower at Fresh Pond where no iron samples exceeded the SMCL. This pattern was consistent with the metals and DO concentrations observed during the USGS 1997-1998 baseline study.

Stony Brook Reservoir historically has the highest surface concentrations of iron and manganese of the three reservoirs. Despite receiving water from Stony Brook, Fresh Pond iron concentrations have been consistently below the 0.3 mg/L SMCL since at least 2000. While median annual surface manganese concentrations at Fresh Pond Reservoir fluctuate above and below the SMCL, manganese is removed during water treatment to meet the 0.05 mg/L SMCL. The decrease in surface iron and manganese concentrations between Stony Brook Reservoir and Fresh Pond Reservoir is likely attributable to a combination of the Fresh Pond aeration system, aeration of the water as in travels through a conduit connecting Stony Brook Reservoir to Fresh Pond Reservoir, and lower concentrations of iron and manganese in the Fresh Pond bed sediments. Median concentrations of iron and manganese at the majority of the 12 tributary sites were higher than the iron and manganese SMCLs. However, iron and manganese concentrations in the reservoirs appeared to be more influenced by internal reservoir processes rather than by the concentrations in the tributaries.

Mirroring the pattern with iron, minimal phosphorus release from the sediments occurred at Fresh Pond in 2018. When comparing surface and bottom samples during thermal stratification, TP and associated indicators of productivity (chl-*a*, TSI, and turbidity) were higher in 2018 summer bottom samples than in surface samples at Hobbs Brook and Stony Brook reservoirs. However, these parameters remained at consistent levels in Fresh Pond.

Although not permitted in the Cambridge drinking water supply, all three reservoirs were of high enough quality to support primary contact recreation in 2018. Geomeans for all reservoir sites during April 1 – October 15 bathing season were below 10 MPN/100 ml, well below the Class A 126 colonies/mL Class A standard. *E. coli* concentrations at all reservoirs were also less than the 235 colonies/100 mL single sample Class A standard except for one sample collected at Stony Brook Reservoir, representing only 2 percent of weekly samples. These results indicate that fecal contamination from human and animal sources was not a water quality concern in the reservoirs. Tributaries were assessed for compliance with the Class A single sample standard for *E. coli* during base-flow conditions. While the exceedance rates were higher than the reservoirs, ranging from 0 percent to 50 percent of base-flow samples per site, only the Indust Brook site median *E. coli* level exceeded the 235 colonies/100 ml recreation standard. Annual median *E. coli* concentrations at the reservoirs and tributaries appeared stable over time and did not indicate increasing or decreasing trends. Except for a short-lived algal bloom in Hobbs Brook Reservoir following a 1.5-inch rainstorm after multiple days above 90 degrees F, CWD did not observe odors, sheens, or algae blooms that could impair the water body aesthetics or impede primary contact with the water in 2018.

Reservoir retention times in 2018 for the Hobbs Brook, Stony Brook, and Fresh Pond reservoirs were 15 months, 15 days, and 3.8 months, respectively. The longer retention time at Hobbs Brook Reservoir indicates that sodium and chloride recovery following the drought will require more time than at Stony Brook and Fresh Pond reservoirs. Stony Brook Reservoir, with only a two-week retention time, can flush the fastest and therefore recover the fastest from changes in water quality.

2 INTRODUCTION

The purpose of this report is to characterize the Cambridge watershed source water quality in 2018 and to evaluate trends in water quality by comparing results against data collected by the Cambridge Water Department (CWD) and the U.S. Geological Survey (USGS) since 1997. Obtaining long-term water quality information is essential in guiding watershed management practices and informing water treatment operations. By understanding where water quality problems exist, CWD can more efficiently and effectively deploy watershed protection resources. CWD staff also use water quality data to evaluate the efficacy of management initiatives and re-prioritize their efforts if necessary.

The CWD source water quality monitoring program was designed by the USGS in cooperation with CWD and is based in part on the results of a 1997 - 1998 comprehensive assessment of reservoir and stream quality (Waldron and Bent, 2001). The assessment, conducted jointly by the USGS and the CWD, included a detailed analysis of the watershed and identified subbasins exporting disproportionate amounts of pollutants to the reservoirs. This information was then used to design the monitoring network which now makes up CWD's long-term source water quality monitoring program.

The USGS/CWD partnership continues to this day and funds "real-time" water quantity and quality monitoring stations, data collection, and interpretive analysis. All data collected by USGS is public record and can be retrieved online from the National Water Information System at this URL:

http://waterdata.usgs.gov/ma/nwis/current?type=cambrid&group_key=NONE&search_site_no_station_nm=&format=html_table

3 WATER SUPPLY NETWORK

The City obtains its water from the 24-square mile Stony Brook watershed (referred to in this report as the Cambridge watershed) located in the towns of Lincoln, Weston, and Lexington and the City of Waltham. This “upcountry” watershed is nested within the Charles River Basin and is comprised of two primary subbasins that feed the Hobbs Brook Reservoir and the Stony Brook Reservoir (Figure 1).

Hobbs Brook and Stony Brook were impounded in the 1890s to create the reservoirs. The Hobbs Brook Reservoir (also known as the Cambridge Reservoir) receives water from its 7-square mile (mi^2) subbasin and discharges into Hobbs Brook through a gatehouse on Winter Street in Waltham (Figure 1). Hobbs Brook joins Stony Brook further downstream, and Stony Brook flows into the Stony Brook Reservoir on the Weston, Waltham town line. From the Stony Brook Reservoir, water flows by gravity through a 7.5-mile underground conduit to Fresh Pond Reservoir, a kettle pond in western Cambridge, located in the Mystic River Basin. Excess water in Stony Brook Reservoir is released into the Charles River.

The Walter J. Sullivan Water Purification Facility is located within the Fresh Pond Reservation in Cambridge and treats water from Fresh Pond Reservoir. Treated water is pumped to the Payson Park underground storage facility in Belmont, MA where it is then fed by gravity to the City’s distribution system (Figure 1). Total capacity at full pool for the Hobbs Brook, Stony Brook, and Fresh Pond reservoirs is roughly 2.5 billion, 418 million, and 1.5 billion gallons, respectively.

During high flow periods (mainly winter and spring), the Stony Brook Reservoir and its subbasin supply the majority of the City’s water demand. During low flow periods (mainly summer and autumn), water released from the Hobbs Brook Reservoir dam supplies most of the City’s daily water demand.

However, in the event of an emergency, the City has a back-up connection to the MWRA (Massachusetts Water Resources Authority) supply. The MWRA supply was used exclusively during the construction of the current Water Treatment Plant from 1999-2001. The City of Cambridge also purchased 848 million gallons (MG) from MWRA in 2016, 18 percent of the total water supplied, due to a combination of infrastructure repairs and periods of low flow during drought conditions. In 2018, MWRA purchases were minimal, totaling only 9.28 MG during the month of August.

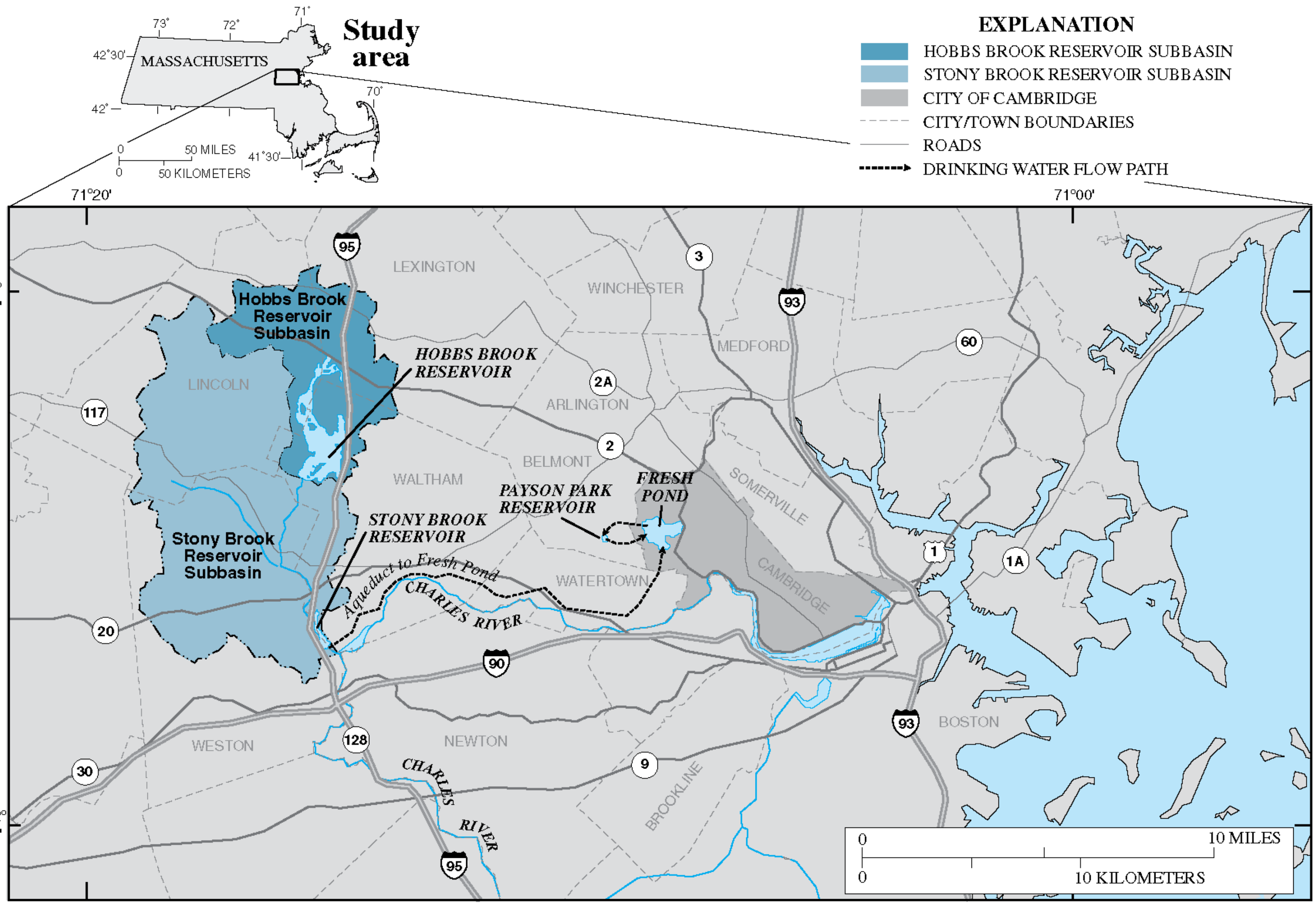


Figure 1: Cambridge Water Supply Source Area

Figure source: Waldron and Bent, 2001

4 Watershed Land Cover Patterns

Based on specific activity, management, and proximity to water resource areas, land use can pose multiple and unique impacts. Understanding how land cover is distributed in the watershed can help predict and mitigate against potential risks and impacts. The 24 square-mile Cambridge watershed is relatively urbanized, with 210 miles of roadway and impervious surfaces covering 14.1 percent of the total area (Table 2 and Table 3; Figure 2, Figure 3, and Figure 4). Growth and development have the potential to negatively impact water quality. However, redevelopment projects may improve water quality by upgrading stormwater treatment systems at older sites. The City of Cambridge only owns and controls approximately 10 percent of watershed lands. This lack of land ownership, along with high land development potential, requires collaboration with watershed stakeholders and regular water quality monitoring to ensure the long-term protection of the water supply.

4.1 Land Cover

In 2019, the Massachusetts Bureau of Geographic Information (MassGIS) published a new GIS Land Cover/Land Use dataset for the year 2016. These shapefiles categorize land cover into 16 different categories. For the purposes of discussing land cover in the Cambridge watershed, the classes have been grouped into 7 categories: agricultural, natural, impervious, wetland, water, open, and bare land (Table 1).

Table 1: MassGIS 2016 land cover name and corresponding CWD category

CWD Category	MassGIS Land Cover 2016 Name
Agricultural Land	Cultivated, Pasture/Hay
Natural Land	Grassland, Deciduous Forest, Evergreen Forest, Scrub/Shrub
Impervious	Impervious
Wetland	Palustrine Forested Wetland, Palustrine Scrub/Shrub Wetland, Palustrine Emergent Wetland, Estuarine Emergent Wetland, Unconsolidated Shore
Water	Water, Palustrine Aquatic Bed
Open	Developed Open Space
Bare	Bare Land

In the Cambridge watershed as a whole, just over half of the land cover consists of natural land, at 51.8 percent by area (Table 2; Figure 2 and Figure 3). In all but one tributary catchment, natural land also comprises the largest percentage of land cover (Table 2 and Figure 3). The Salt Depot catchment has the largest percentage of natural land, at 67.9 percent. The only catchment where natural land does not represent the largest land cover type is Industrial Brook. Here, impervious cover is the dominant the land cover type for the catchment at 64.7 percent. Industrial Brook is the smallest tributary catchment in the watershed.

Across the entire watershed, impervious cover accounts for 14.1 percent of the land cover (Table 2; Figure 2 and Figure 3). However, impervious cover is not evenly distributed throughout the watershed subcatchments. The HB @ Mill St catchment has the lowest percentage of impervious cover, at 5.9 percent (Table 2 and Figure 2). SB @ Viles has the second lowest amount of impervious cover (8.3 percent) and is the largest tributary catchment apart from RT 20, which receives flow from SB @ Viles. The highest percentage of impervious cover is found in the Indust Brook catchment.

Table 2: The breakdown of MassGIS 2016 land cover by category for CWD tributary monitoring site catchments

Site Name	Catchment Area (mi^2)	Land Cover (% area)						
		Natural	Impervious	Water	Wetland	Agricultural	Open	Bare
HB @ Mill St	2.15	49.7	5.9	3.9	29.6	3.6	6.7	0.6
Salt Depot	0.34	67.9	17.1	0.0	9.9	0.0	5.1	0.0
Lexington Brook	0.47	43.8	33.0	0.0	1.6	0.9	20.7	0.0
Tracer Lane	0.75	35.4	30.7	0.0	16.4	0.0	17.4	0.1
HB Below Dam	6.95	46.7	17.1	12.2	12.3	1.3	10.2	0.2
SB @ Viles	10.4	55.5	8.3	3.5	19.1	4.1	9.0	0.5
Industrial Brook	0.36*	14.1	64.7	0.2	8.9	0.0	12.1	0.0
HB @ KG (Hobbs Open)	8.48	47.1	19.1	10.2	11.9	1.0	10.4	0.3
HB @ KG (Hobbs Closed)	1.49	49.3	28.1	1.0	10.1	0.0	11.1	0.4
WA-17	0.50	38.7	37.1	0.3	1.6	0.0	12.9	9.4
MBS	2.23	54.8	14.1	2.8	14.6	0.5	13.1	0.1
RT 20 (Hobbs Open)	22.0	51.6	14.0	6.0	15.3	2.4	10.1	0.6
RT 20 (Hobbs Closed)	15.0	54.0	12.5	3.1	16.7	3.0	10.0	0.9
Summer Street	0.80	57.3	12.0	1.0	4.7	2.0	22.9	0.1
Cambridge Watershed (Hobbs Closed)	**16.6**	**53.9**	**13.6**	**9.8**	**14.8**	**2.8**	**4.4**	**0.7**
Cambridge Watershed	**23.6**	**51.8**	**14.1**	**6.1**	**14.6**	**2.3**	**10.5**	**0.6**

*0.33 mi^2 is the effective drainage area of the Industrial Brook catchment (Smith, 2013)

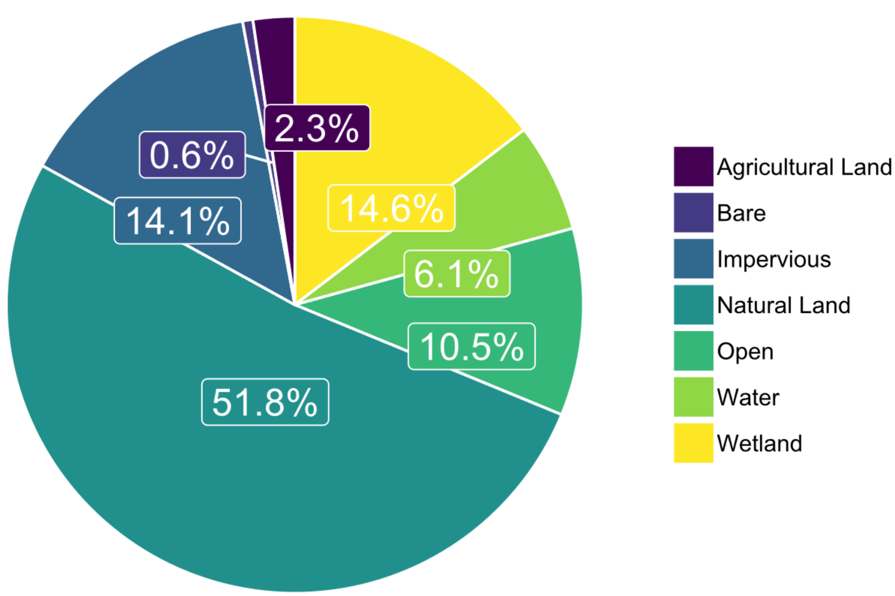


Figure 2: Cambridge watershed land cover percentages, 2016

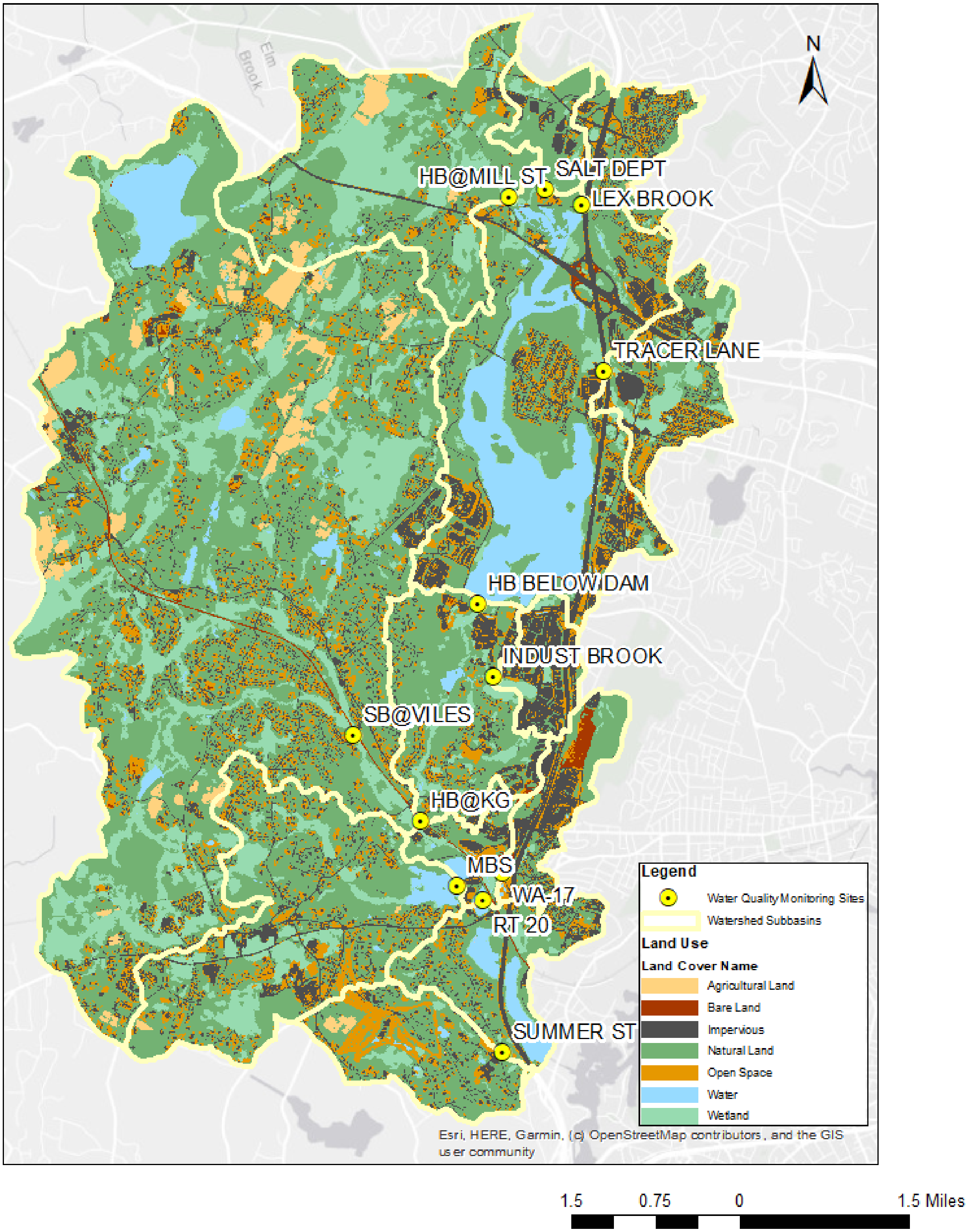


Figure 3: Cambridge watershed land cover, 2016. Data sources: MassGIS, USGS, CWD.

Wetlands account for 14.6 percent of the Cambridge watershed (Table 2; Figure 2 and Figure 3). The catchments with the largest percentage of wetlands are HB @ Mill Street and SB @ Viles at 29.6 percent and 19.1 percent, respectively (Table 2).

Open water only comprises 6.1 percent of the Cambridge watershed (Table 2; Figure 2 and Figure 3). The HB Below Dam catchment has the largest percentage of open water at 12.2 percent because of the large Hobbs Brook Reservoir footprint.

Developed open space is land that is not in a natural state but is not considered impervious. Open space makes up 10.5 percent of the land cover by area in the Cambridge watershed (Table 2; Figure 2 and Figure 3). All catchments have some open space present, most typically as lawns around residences and offices. The Summer St catchment has the highest percentage of open space at 22.9 percent, the bulk of which is a golf course (Table 2 and Figure 3). The smallest percentage of open space is found in the Salt Depot catchment, although the proportion of natural land is high.

Agriculture is not a major land cover type in the Cambridge watershed at just 2.3 percent by area (Figure 2). Many of the catchments have no agricultural land cover at all (Table 2). The highest percentage of agricultural land cover is found in the SB @ Viles St catchment, but even then, only at 4.1 percent.

Bare land cover contributes only 0.6 percent of the total Cambridge watershed land area (Table 2; Figure 2 and Figure 3). Bare land is not natural land, not necessarily impervious but not vegetated either. Bare land areas are usually sites of planned, ongoing, or past construction work. Except for WA-17, every catchment is covered by less than 1 percent bare land (Table 2). The WA-17 catchment has 9.4 percent bare land cover by area, the result of an ongoing redevelopment project at 1265 Main Street in Waltham (Table 2 and Figure 3).

In the case of the RT 20 and HB @ KG monitoring sites, the tributary catchment areas actually change seasonally based on when Cambridge draws water from the Hobbs Brook Reservoir (Table 2). The proportion of land cover categories for the RT 20 catchment happens to stay mostly consistent whether the Hobbs Reservoir is discharging flow or not. On the other hand, the HB @ KG tributary catchment impervious cover increases by nearly 10 percentage points when the Hobbs Brook Reservoir is closed.

4.2 Roadways

Roadways are important in the watershed because of the stormwater runoff generated that can discharge untreated into nearby resource areas. In the winter specifically, roads are treated with deicing chemicals to prevent ice formation, but there are contaminants on roads year-round. Roads also place nearby waterways at risk of petroleum or chemical spills from vehicles and their cargo. Due to these potential risks and impacts, it is important to understand the location and extent of roads in the watershed.

The Cambridge watershed is relatively developed, with an accompanying comprehensive network of roadways (Figure 4). In the 24 square-mile watershed, there are 210 linear miles of road and 8.9 miles of road per square mile (Table 3). Road types are varied throughout the watershed, from residential to interstate highway. The miles of road for each catchment were calculated using the TIGER roads layer generated from the 2010 census and downloaded from the MassGIS OLIVER tool. The data layer does not account for lane miles. For example, a one-mile road segment with one lane was calculated to have the same length as a one-mile segment with three lanes.

Since RT 20 is the largest catchment in the watershed, it is unsurprising that it also has the most miles of roadway (Table 3). The RT 20 catchment includes the Hobbs Brook Reservoir which directly abuts I-95, a major highway with many lanes in both directions (Figure 4). The HB Below Dam and HB @ KG (when the dam is open) catchments also include this stretch of roadway.

SB @ Viles is the second largest catchment, with 66.5 miles of road (Table 3). However, its road density is tied for the lowest with HB @ Mill St at 6.4 mi/mi^2. The SB @ Viles catchment has only 8.3 percent impervious cover by area, the second lowest of any catchment in the watershed, reflecting the lower density of development compared to RT 20.

Industrial brook is the second smallest catchment, at only 0.36 mi^2. It has 6.16 miles of roadway, which is almost 3 times the miles of road in the Salt Depot catchment, which is closest in size at 0.34 mi^2 (Table 3). Due to the small area, Industrial Brook has one of the highest road densities, at 17.1 mi/mi^2. Industrial Brook also has the greatest percentage of impervious cover of any of the catchments (64.7 percent).

Table 3: Cambridge watershed catchment areas, roadway miles (2010), and impervious cover (2016)

Site Name	Catchment Area (mi^2)	Impervious (%)	Road (mi)	Miles of Road per mi^2 of catchment
HB@ Mill St	2.15	5.9	13.8	6.4
Salt Depot	0.34	17.1	2.32	6.8
Lexington Brook	0.47	33.0	11.6	24.8
Tracer Lane	0.75	30.7	12.9	17.1
HB Below Dam	6.95	17.1	76.9	11.1
SB @ Viles	10.4	8.3	66.5	6.4
Industrial Brook	0.36*	64.7	6.16	17.1
HB @ KG (Hobbs Open)	8.48	19.1	91.2	10.8
HB @ KG (Hobbs Closed)	1.49	28.1	14.4	9.6
WA-17	0.50	37.1	10.1	20.2
MBS	2.23	14.1	21.5	9.6
RT 20 (Hobbs Open)	22.0	14.0	192	8.8
RT 20 (Hobbs Closed)	15.0	12.5	115	7.7
Summer Street	0.80	12.0	6.39	8.0
Cambridge Watershed (Hobbs Closed)	**16.6**	**13.6**	**133**	**8.0**
Cambridge Watershed	**23.6**	**14.1**	**210**	**8.9**
*0.33 mi^2 is the effective drainage area of the Industrial Brook catchment (Smith, 2013)				

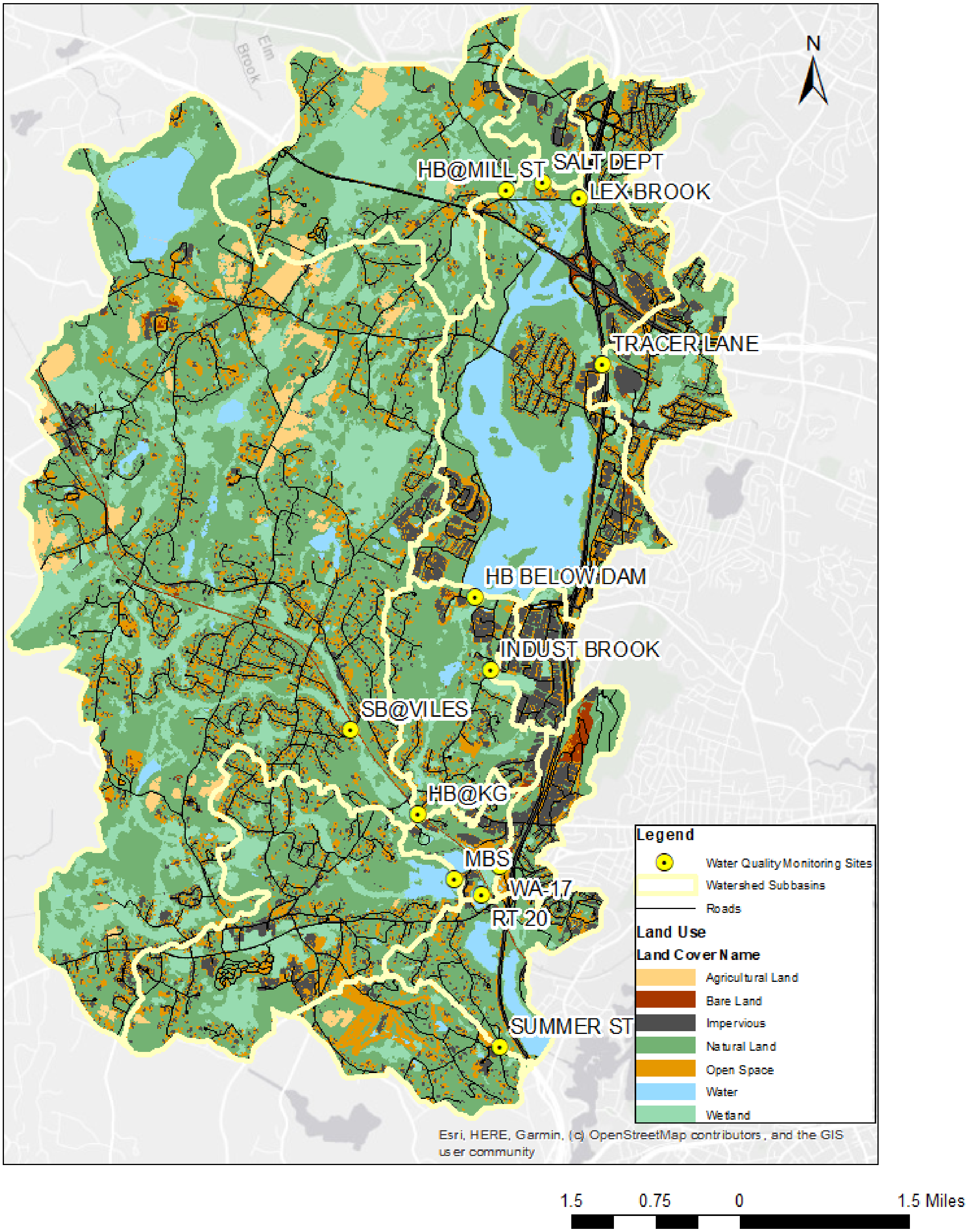


Figure 4: Land use cover (2016) and roads (2010) in the Cambridge watershed. Data sources: MassGIS, USGS, CWD.

5 CAMBRIDGE SOURCE WATER QUALITY MONITORING PROGRAM

5.1 MONITORING OBJECTIVES AND PROGRAM OVERVIEW

Given the City's lack of ownership and control of most watershed lands, water quality monitoring is a necessary and effective means of identifying sources of pollution and tracking water quality changes over time. The primary goal of the Cambridge Source Water Quality Monitoring Program is to ensure that water withdrawn from Fresh Pond Reservoir for treatment is as free as possible from contaminants, thereby minimizing the costs of treatment and protecting overall water quality. Specific objectives of the program are to:

- Provide for rapid response to real-time and emerging problems.
- Monitor the condition of source waters in the Cambridge drinking water supply system;
- Determine where, when, and how water quality conditions are changing over time;
- Identify actual and potential problems related to source water quality;
- Evaluate the effectiveness of programs designed to prevent or remediate water quality problems; and
- Ensure that all applicable water quality goals, standards, and guidelines are being met

The Cambridge Source Water Quality Monitoring Program consists of four major elements: (1) routine monitoring of reservoirs and tributaries during base-flow (dry weather) conditions and weekly monitoring of reservoirs (all conditions) (2) continuous recording of stage and selected water quality characteristics at critical sites within the drainage basins (3) event-based monitoring of streams, storm drains, and other outfalls during wet weather and special water quality investigations and (4) data management, quality control, analysis and reporting. Results of the sampling program are compared against various state and federal regulations, criteria, and standards.

5.2 MONITORING EQUIPMENT AND SAMPLE COLLECTION PROTOCOLS

CWD measures temperature, dissolved oxygen (DO), specific conductance, total dissolved solids (TDS), and pH *in situ* using a calibrated Eureka Water Probes Manta2™ Multiprobe. Grab samples are also collected from streams and reservoirs using 1 Liter Teflon bottles for nutrients and high-density polyethylene (HDPE) bottles for all other parameters. A peristaltic pump and pre-cleaned Tygon tubing are used for collecting samples from bottom depths of the reservoirs. All tributary monitoring sites are sampled from the stream center using the centroid dip technique (Edwards and Glysson, 1999).

All samples are transported back to the Walter J. Sullivan Purification Facility on ice for processing. A contracted laboratory analyzes samples for total Kjeldahl nitrogen (TKN), ammonia as nitrogen, total phosphorus (TP), and chlorophyll-*a* (chl-*a*). The CWD laboratory performs the tests for all other parameters. Water quality samples are collected by CWD at using *Clean Water* protocols (Wilde and others, 1999) for all aspects of sample collection, preservation, and transport.

5.3 Routine Reservoir and Tributary Base-flow Water Quality Monitoring

5.3.1 Routine dry weather reservoir monitoring

The Hobbs Brook Reservoir is divided into three basins by State Route 2, Trapelo Road, and Winter Street (Figure 5). Hobbs Brook Reservoir has four monitoring sites, two of which are sampled from the shoreline (HB @ Upper and HB @ Middle), and the other two (HB @ DH and HB @ Intake), are sampled by boat at fixed mooring locations (Figure 5). Stony Brook Reservoir has two sites (SB @ DH, and SB @ Intake), and Fresh Pond Reservoir has three sites (FP @ Cove, FP @ DH, FP @ Intake), all sampled by boat.

Surface grab samples in 2018 were collected by CWD during dry weather 6 to 7 times in each reservoir and analyzed for *E. coli* bacteria, alkalinity, color, chl-*a*, select metals and nutrients, pH, specific conductance, total organic carbon (TOC), and turbidity. The Eureka Water Probes Manta2™ probe was used to measure additional physical and chemical parameters (Table 4 and Table 5). During the spring, summer and early fall months, when the water column was thermally stratified, additional water quality grab samples were collected from one meter above the reservoir bottoms.

Water quality profiles of temperature, DO, specific conductance, pH, and TDS were also collected between 6 and 9 times at each reservoir site during dry conditions (Table 4 and Table 5). Water quality profiles began at 0.3 meters below the reservoir surface and the Manta2™ Multiprobe recorded measurements every 1 to 2 meters in depth down to one meter above the reservoir bottom. The profiles were used to monitor thermal and chemical stratification within the reservoirs, and to inform the operation of an aeration system at Fresh Pond.

5.3.2 Weekly reservoir monitoring

In addition to the routine dry weather reservoir monitoring program, CWD collects weekly surface grab samples, regardless of the weather, from inside the Hobbs Brook Dam and Stony Brook Dam gatehouses (HB @ Intake Weekly and SB @ Intake Weekly). During weeks when the Hobbs Brook Reservoir is frozen, the sample is collected downstream of the gatehouse at the dam outlet. When weekly sampling events coincided with a routine dry-weather reservoir sampling event, the weekly samples are collected from the HB @ Intake and SB @ Intake boat sites instead of inside the gatehouse (Figure 5).

Weekly samples help to identify immediate contamination, capture seasonal and climatic water quality variability, and track chemical concentration changes over time. Weekly samples are analyzed for *E. coli* bacteria, alkalinity, color, select metals, pH, specific conductance, TOC, and turbidity.

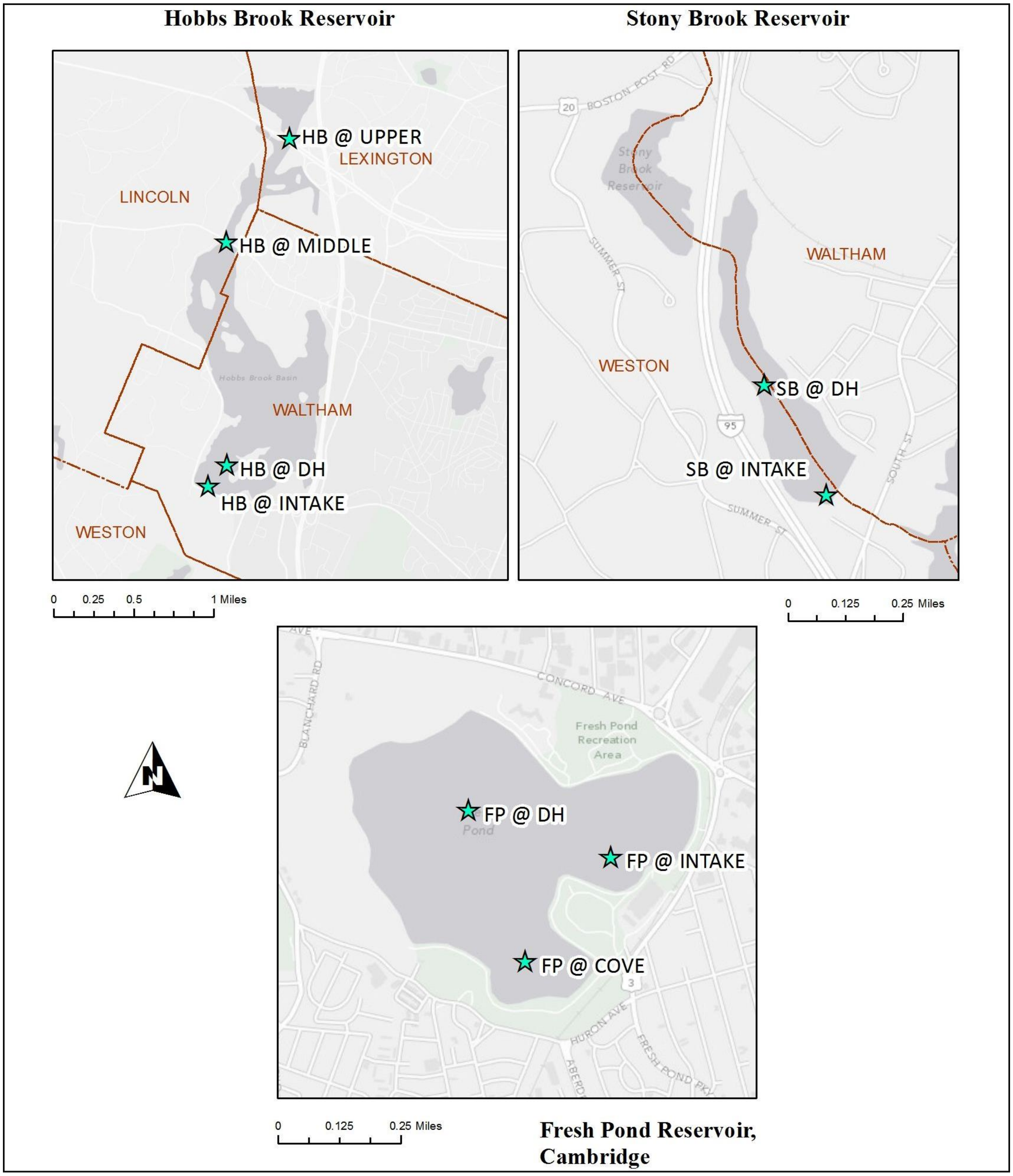


Figure 5: Reservoir Sampling Locations

Table 4: Number of routine dry-weather reservoir sampling events by parameter and site, 2018

S = surface (0-0.3 m depth); B=0.5 m from the reservoir bottom; P = water quality profile, measurements collected at 0.3 m depth and every 1 – 2 m in depth. SpC = specific conductance.
- - indicates that the site or location was not sampled for the given set of parameters.

		HB @ Upper	**HB @ Middle**	**HB @ DH**			**HB @ Intake**			**SB @ DH**			**SB @ Intake**			**FP @ DH**			**FP @ Cove**	**FP @ Intake**		
Parameters		**S**	**S**	**S**	**B**	**P**	**S**	**B**	**P**	**S**	**B**	**P**	**S**	**B**	**P**	**S**	**B**	**P**	**P**	**S**	**B**	**P**
Manta2™ Multiprobe Reading, *measured in situ*	DO SpC Temperature pH TDS	6	6	6	6	6	6	6	6	6	6	6	6	6	6	9	9	9	9	9	9	9
Secchi Disk Depth, *measured in situ*	Secchi Disk Depth	--	--	6	--	--	6	--	--	6	--	--	6	--	--	9	--	--	9	9	--	--
Water Quality Grab Samples, *Analyzed by CWD laboratory*	Al Alkalinity Ca^{2+} Cl^- Color Fe Mn Na^+ NO_3^- / NO_2^* pH SpC TOC Turbidity	6	6	6	4	--	--	--	--	6	4	--	--	--	--	7	4	--	--	--	--	--
	E. coli	6	6	--	--	--	6	--	--	--	--	--	6	--	--	--	--	--	--	7	--	--
Water Quality Grab Samples, *Analyzed by contract laboratory*	Chl-*a* NH_3 TKN TP	6	6	6	4	--	--	--	--	6	4	--	--	--	--	7	4	--	--	--	--	--

*NO_3^-/NO_2^+ samples were analyzed by a contract lab if scheduling conflicts prevented CWD staff from performing the analysis in house.
If a sample was unable to be analyzed for a parameter, for example in the case of laboratory instrument failure or contamination, the absence is noted the report.

Table 5: Reservoir base-flow sampling events by date and site, 2018

M=Manta2™ Multiprobe surface reading; MP = Manta2™ Multiprobe water column profile; E = E. coli sample; WL = water quality sample analyzed by CWD laboratory (except E. coli); WC = water quality grab sample analyzed by contract laboratory; B = bottom grab sample analyzed for WL and WC parameters. See Table 4 for list of parameters analyzed by the Manta2™ Multiprobe, CWD laboratory (WL), and contract laboratory (WC).

Date	Feb	Mar	April		May	June		Jul			August			Sept		Oct	Nov		Dec	
	15	27	3	11	2	13	21	3	5	11	7	8	30	5	25	9	1	8	5	12
HB @ Upper	M, E, WL, WC	M, E, WL, WC							M, E, WL, WC				M, E, WL, WC						M, E, WL, WC	
HB @ Middle	M, E, WL, WC	M, E, WL, WC							M, E, WL, WC				M, E, WL, WC						M, E, WL, WC	
HB @ DH				MP, WL, WC			MP, WL, WC, B			MP, WL, WC, B		MP, WL, WC, B			MP, WL, WC, B		MP, WL, WC			
HB @ Intake				MP, E			MP, E			MP, E		MP, E			MP, E		MP, E			
SB @ DH				MP, WL, WC			MP, WL, WC, B			MP, WL, WC, B		MP, WL, WC, B			MP, WL, WC, B		MP, WL, WC			
SB @ Intake				MP, E			MP, E			MP, E		MP, E			MP, E		MP, E			
FP @ DH			MP, WL, WC		MP	MP, WL, WC, B		MP, WL, WC, B			MP, WL, WC, B			MP, WL, WC, B		MP		MP, WL, WC		MP, WL, WC
FP @ Cove			MP		MP	MP		MP			MP			MP		MP		MP		MP
FP @ Intake			MP, E		MP	MP, E		MP, E			MP, E			MP, E		MP		MP, E		MP, E

5.3.3 Routine tributary base-flow monitoring

CWD conducts base-flow sampling at 12 tributary sites on days with no more than 0.10 in of rain within the prior 72 hours (Figure 6). Or, CWD collects base-flow samples within less than 72 hours of a storm event if real-time continuous stage, temperature, and specific conductance data indicates that the stream has returned to base-flow conditions. CWD collected surface water quality grab samples from each tributary site five to seven times in 2018 and analyzed the samples for the same parameters as the reservoirs, except for chl-*a* (Table 6 and Table 7). The Manta2™ Multiprobe was also used to capture snapshots of DO, pH, specific conductance, temperature, TDS, and pH six to eight times at each site (Table 6 and Table 7).

Through a joint funding agreement (JFA) between the City of Cambridge and the USGS, USGS also collected water quality grab samples in 2018, including base-flow samples. See Appendix A for a list of CWD site names and corresponding USGS station numbers.

USGS water quality results are publicly accessible through the agency's website:
https://nwis.waterdata.usgs.gov/ma/nwis/qwdata.

5.4 Continuous Watershed Monitoring Stations

Nine of the 12 primary tributary sites, as well as all three reservoirs, were equipped with USGS stations in 2018 that continuously monitored (10-15 minute data collection interval) stream and reservoir stage as part of the JFA between CWD and USGS (Figure 6). Reservoir storage and reservoir discharge (calculated based on stage readings) were also continuously tracked by USGS. Temperature, specific conductance, stream discharge (based on stage), and other water quality parameters such as chl-*a* and turbidity were also collected continuously at a subset of stations. Precipitation was monitored at the three reservoir stations, and wind speed and direction were measured at the Stony Brook Reservoir. Data from these sites are available in real time on the USGS website:

(http://waterdata.usgs.gov/ma/nwis/current/?type=cambrid&group_key=basin_cd&site_no_name_select=siteno).

CWD maintains a HOBO-U20L water level logger, installed in October of 2016, that collects 15-minute water level and temperature data at HB @ KG. Using a CWD-generated stage-discharge relationship (rating curve), CWD maintains a database of continuous calculated discharge at the site. CWD also collects periodic instantaneous discharge measurements (approximately 6 measurements per year) using a SonTek FlowTracker® handheld Acoustic Doppler Velocimeter (ADV®) to maintain the rating curve, applying shifts to the rating curve as needed.

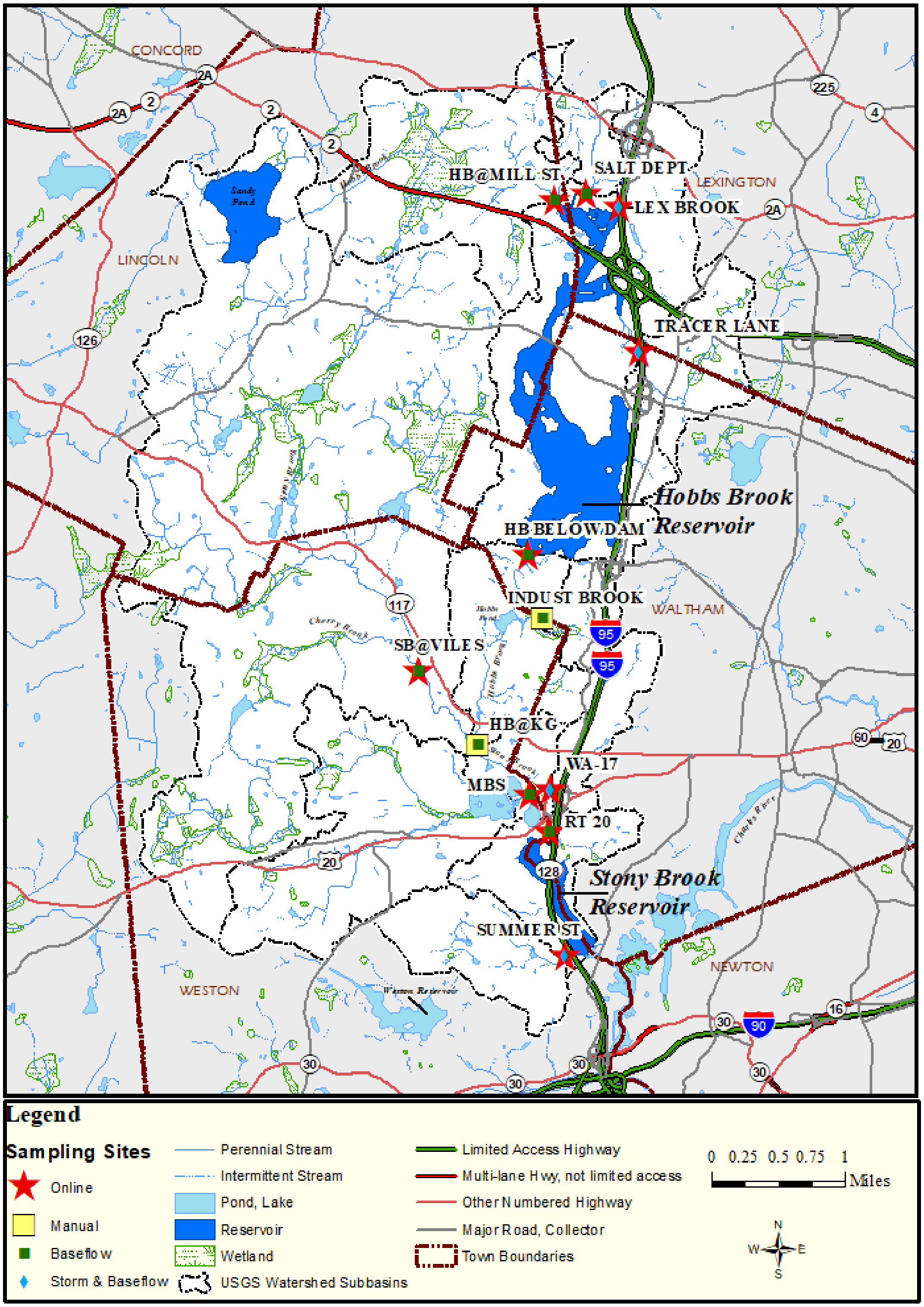


Figure 6: Tributary monitoring station locations within the Cambridge Watershed

Table 6: Number of tributary base-flow surface sampling events by parameter and site, 2018

Parameters		HB @ Mill St	Salt Depot	Lex Brook	Tracer Ln	HB Below Dam	Indust Brook	HB @ KG	SB @ Viles St	MBS	WA-17	RT 20	Summer St
Manta2™ Multiprobe Reading, *measured in situ*	DO SpC Temperature pH TDS	6	7	8	7	7	6	6	7	7	7	7	8
Water Quality Grab Samples, *Analyzed by CWD laboratory*	Al Alkalinity Ca Cl^- Color Fe Mn Na^+ NO_3^- / NO_2* pH SpC TOC Turbidity *E. coli*	7	7	7	7	7	6	6	6	7	7	7	7
Water Quality Grab Samples, *Analyzed by contract laboratory*	NH_3 TKN TP	7	7	7	7	7	6	6	5	7	7	7	7

*NO_3^-/NO_2^+ samples were analyzed by a contract lab if scheduling conflicts prevented CWD staff from performing the analysis in house.
If a sample was unable to be analyzed for a parameter, for example in the case of laboratory instrument failure or contamination, the absence is noted the report.

Table 7: Tributary base-flow surface sampling events by date and site, 2018

Unless otherwise indicated, all sampling events included a Manta2™ Multiprobe reading, E. coli sample, and all water quality grab sample parameters analyzed by the CWD laboratory and contract laboratory. See Table 6 *for list of parameters analyzed by the Manta2™ Multiprobe, CWD laboratory, and contract laboratory. X = sampling date.*

Date	**Jan**	**Feb**		**Mar**				**Apr**	**May**		**June**		**Jul**		**Aug**				**Oct**		**Dec**		
	9	**1**	**15**	**1**	**20**	**27**	**28**	**10**	**10**	**15**	**12**	**13**	**5**	**12**	**13**	**20**	**29**	**30**	**10**	**18**	**5**	**6**	**13**
HB @ Mill St		X			X			X			X						X*			X			X
Salt Depot		X			X			X			X						X			X			X
Lex Brook	X			X			X		X					X	X^				X			X	
Tracer Ln		X			X			X			X						X			X			X
HB Below Dam	X			X			X		X					X					X			X	
Indust Brook			X			X				X			X					X			X		
HB @ KG			X			X				X			X					X			X		
SB @ Viles		X				X		X				X				X^		X$^{\#}$			X		
MBS		X			X			X				X					X			X			X
WA-17	X			X			X		X					X					X			X	
RT 20	X			X			X		X					X					X			X	
Summer St	X			X			X		X					X		X^			X			X	

*No Manta2™ Multiprobe readings due to sensor error. ^Manta2™ Multiprobe readings only. $^{\#}$No contract laboratory samples were collected (TP, TKN, or NH_3)

5.5 Event-Based Water Quality Monitoring

5.5.1 Stormwater Sampling

Wet weather or stormwater sampling by staff in the field can be difficult to schedule due to the unpredictable timing of precipitation events. Thus, automatic sampling is a preferred method for obtaining wet weather samples. USGS continuous monitoring stations at Lex Brook, Tracer Ln, WA-17, and Summer St are equipped with automatic samplers which collect storm water when triggered by high stream flow (Figure 6). USGS storm sample collection dates for 2018 are presented below in Table 8. The range of dates indicates the duration of the storm from which the composite sample was derived. Results from USGS stormwater sampling in 2018 are presented in this report, but are also publicly accessible from the USGS website:

https://nwis.waterdata.usgs.gov/ma/nwis/qwdata

Table 8. USGS Wet Weather Sampling Dates, 2018

Site	Lex Brook	Tracer Ln	WA-17	Summer St
USGS Site ID	**01104415**	**01104420**	**01104455**	**01104475**
USGS Wet Weather Sampling Dates	4/3-4/5	4/3-4/4	4/3-4/4	4/3-4/5
	5/15-5/16	5/15-5/16	5/15-5/16	5/15-5/16
			6/4	6/4-6/5
	6/28	6/27-6/29		6/28-6/29
		7/6-7/7		
		10/27-10/28	10/27-10/28	10/27-10/29
	11/2-11/4			
	11/9-11/10	11/9-11/10	11/9-11/10	11/9-11/11

5.5.2 Incident-Based Sampling

CWD staff perform additional sampling on an as-needed basis to investigate problems associated emergency spills or illicit discharges within the watershed, and to monitor runoff from construction activities. These test results help guide spill response and enforcement activities within the watershed and are not included in this report.

5.6 Data Management, Quality Control, Analysis and Reporting

5.6.1 Data Management, Data Analysis, and Reporting

All water quality monitoring and quality-assurance data are entered into a CWD-maintained database that enables the CWD analyze, track, and report changes in water quality efficiently. This report satisfies the reporting portion of the Cambridge Source Water Quality Monitoring Program. Source water quality data is available upon request. To submit a data request, email joconnell@cambridgema.gov.

5.6.2 Quality Control

Field duplicates and field blanks provide quality control checks on CWD data. Field duplicates, when a second or "duplicate" sample is collected during a sampling event, are a measure of sample precision and environmental variability. Field blanks ensure there is no cross-contamination of the samples during sample collection, transport, and processing.

When field duplicate samples were collected, results and statistics presented in this report were calculated using the mean concentration of the sample and duplicate sample. For example, when tallying the total number of samples at a site, the mean of the sample and duplicate was reported as a single sample rather than two separate samples. If a sample was below the detection limit, the sample was set to the detection limit in order to average the two samples. Assigning a value of the detection limit errs on the side of overestimating rather than under estimating parameter concentrations.

See Appendix B for 2018 quality control results.

6 BOXPLOT KEY

All boxplots presented in this report use the format shown in Figure 4. The median was included in the 25th and 75th percentile calculations. The inter quartile range (IQR) was calculated as the difference between the 75th and 25th percentiles (Figure 7). Sample results below the detection limit were set to the detection limit for the purposes of generating the boxplot and calculating the boxplot statistics and other reported statistics.

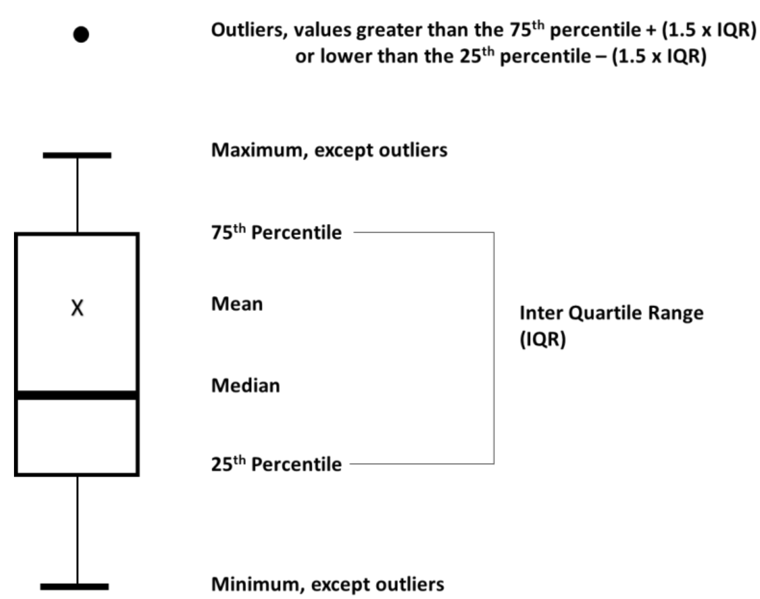


Figure 7: Boxplot Key

7 COMPARATIVE WATER QUALITY STANDARDS AND PARAMETERS

CWD evaluated water quality results against three different sets of standards and guidelines: Massachusetts Surface Water Quality Standards, Massachusetts Drinking Water Standards and Guidelines, and U.S. Environmental Protection Agency (EPA) nutrient criteria. A description of each set of standards or guidelines is provided in the following sections.

7.1.1 Massachusetts Surface Water Quality Standards (Class A standards)

The Massachusetts Class A ambient surface water quality standards (Class A standards) are set by the Massachusetts Department of Environmental Protection (MA DEP) (314 CMR 4.00) and were created to implement the Massachusetts Clean Water Act. The MA Clean Water Act requires MA DEP to define permissible uses for all water bodies in Massachusetts and to define minimum water quality criteria necessary to maintain those uses. All drinking water reservoirs and their associated tributaries are considered Class A. Examples of designated uses relevant to Class A waters in the Cambridge watershed include: Public Water Supply, Aquatic Life, Aesthetics, and Primary and Secondary Contact Recreation (even where recreation is not allowed) (314 CMR 4.05 (3) (a) and Massachusetts Division of Watershed Management Watershed Planning Program, 2016).

The 314 CMR 4.00 regulations define numerical ambient surface water quality standards for *E. coli*, DO, pH, and temperature. The regulations also contain narrative descriptions to define water quality requirements for color and turbidity, oil and grease, taste and odor, aesthetics, bottom pollutants or alterations, nutrients, radioactivity, and toxic pollutants (such as chloride, ammonia, and various metals). The Massachusetts Consolidated Assessment and Listing Methodology Guidance Manual for the 2016 Reporting Cycle (CALM) expands upon the metrics and narratives in 314 CMR 4.00, defining the methods used by MA DEP to assesses whether water bodies meet their designated uses per the surface water quality standards outlined in 314 CMR 4.00.

Parameters measured by CWD and compared to the MA Surface Water Quality Standards are summarized in Table 9 below. MA DEP analyzes many different factors to determine whether water bodies meet their uses or are impaired. The metrics analyzed by CWD are only a subset of the factors analyzed by MA DEP to characterize the health of a water body.

Despite being defined as a use, MA DEP does not assess whether water bodies meet the Public Water Supply use under the MA Clean Water Act (Massachusetts Division of Watershed Management Watershed Planning Program, 2016). Instead, MA DEP determines if water is safe to drink based on standards for finished (treated) water under the Safe Drinking Water Act (see Section 7.1.2 *Massachusetts Drinking Water Guidelines and Standards*).

Table 9: Selected Massachusetts Surface Water Quality Standards and designated Uses for Class A water bodies

Category	Criteria	Uses	Description
Bacteria (*E. coli*)	≤235 colonies/100 mL (single sample) ≤126 colonies/100 mL (geomean for most recent 6-month period)	Primary Contact Recreation	This *E. coli* bacteria serotype is found in the digestive systems of warm-blooded animals and is used as an indicator for sewage-related pathogens. 314 CMR 4.05 (3) defines two standard types for *E. coli*. No single sample may exceed 235 Colonies/100mL, while the geomean for the most recent 6-month period may not exceed 126 colonies/100 mL. CWD uses an *E. coli* analysis technique that estimates the *most probable number* [MPN] of colonies per 100 ml. The criterion is less stringent for the secondary contact recreation use (geomean ≤ 630 colonies/100 mL).
Dissolved Oxygen (DO)	≥ 5 mg/L (warm water fisheries) ≥ 6 mg/L (cold water fisheries (CFRs) [1]	Aquatic Life	DO is critical in supporting a healthy fish and aquatic wildlife population. Low DO and anoxic conditions can also release nutrients from sediments and mobilize metals such as iron and manganese which become nuisances during water treatment. DO should not be lower than the Class A standard unless natural background conditions are lower. Large diel changes in DO concentration (> 3 mg/L) may be a sign of nutrient impairment. Primary producers generate DO from photosynthesis during the day and respire at night, resulting in a daily flux in DO.
pH	6.5≥ pH ≤ 8.3, or no more than 0.5 standard units outside of background conditions	Aquatic Life	pH is a measure of acidity in water and is defined as the -log[H^+]. Water with a pH level of 7 is considered neutral; water with a pH below 7 is acidic and above 7 is basic. pH influences the solubility, reactiveness, and bioavailability of various nutrients and heavy metals. Waters with pH outside of the Class A range can be harmful to fish and wildlife. As with DO, large diel fluxes in pH may indicate nutrient impairment due to high productivity. Elevated pH (low acidity) during the day may indicate high biological productivity due to the uptake of carbon dioxide (CO_2) during photosynthesis. This uptake prevents CO_2 from mixing with water (H_2O) and forming bicarbonate (HCO_3^-) and H^+ molecules. Similarly, pH in waters with high productivity may drop at night (increase in acidity) as organisms respire and produce CO_2.
Temperature	≤28.3 degrees C (warm water fisheries) 7-DADM ≤20 degrees C (CFRs)	Aquatic Life	Certain aquatic species are temperature sensitive and require cooler water to survive. Warm water holds less DO than cold water, increases rates of chemical reactions, can promote harmful biological growth such as algae blooms, and increases the toxicity of certain pollutants to wildlife. 7-DADM = Seven-day average daily maximum temperature

[1] Coldwater fish resources (called cold water fisheries in 314 CMR 4.00) are defined by the Massachusetts Division of Fisheries and Wildlife.

Table 9. *Continued*			
Category	**Criteria**	**Uses**	**Description**
Nutrients and Eutroph-ication	<u>Reservoirs:</u> chl-*a*, ≤16 mg/m^3 non-rooted macrophyte(s) and/or algae lake area coverage, ≤25% TP, ≤0.025 mg/L* for summer seasonal average with sample size≥3 SD≥1.2 meters <u>Tributaries and Reservoirs:</u> pH<8.3 No harmful algal blooms; sheens; odors, excessive trash, turbidity, or plant and algal growth	Aquatic Life Aesthetics Primary Contact Recreation Secondary Contact Recreation	Excess nutrients can lead to eutrophication, a process by which a water body evolves from a lower to higher capacity to support biological productivity. Human activity can expedite this process by introducing nitrogen, phosphorus, and other biologically useful nutrients to a waterway in quantities that would normally not be present. Water bodies with more nutrients available can support more life, which eventually may lead to harmful algae blooms, overgrowth of plant life, turbidity and reduced visibility, and a hostile environment for animal life due to lack of oxygen. When excess nutrients result in loss of visibility as measured by Secchi depth (SD) and excessive plant or algae growth, waters can also be impaired for aesthetics and recreational uses. MA DEP has not yet adopted numerical criteria for specific nutrients. Instead, MA DEP evaluates whether waters support the Aquatic Life use with respect to nutrients based multiple primary producer biological and physico-chemical screening guidelines such as chl-*a*, macrophyte coverage, SD transparency, pH, DO, and TP. CWD nutrient results were also compared against EPA nutrient criteria for TP, total nitrogen (TN), TKN, and nitrate and nitrite nitrogen, although these criteria are not used by MA DEP. See Section 7.1.3 *EPA Nutrient Criteria*. Criteria listed in this table only pertain to parameters monitored by CWD. The MA DEP list is more extensive.
Chloride	230 mg/L (four-day average), chronic[2] 860 mg/L (one-hour average), acute[3]	Aquatic Life	Chloride is a dissolved ion that, along with sodium, is present naturally in the environment. However, chloride is often elevated by anthropogenic sources such as sodium chloride from road salt. Elevated chloride concentrations can be harmful to aquatic life and can also cause drinking water to taste "salty." The 2016 DEP CALM guidance uses the EPA-defined chronic and acute toxicity criteria to make impairment decisions. For the purposes of this study, grab sample results were compared against the 230 mg/L criterion, although continuous data are necessary to confirm that observed exceedances hold over a four-day average.
Sources: 314 CMR 4.05; Massachusetts Division of Watershed Management Watershed Planning Program, 2016 *MA DEP uses the 1986 EPA Gold Book criteria for TP			

[2] Grab samples that exceed 230 mg/L would lead to a recommendation by MA DEP for further study to determine whether the water chemistry exceeds 230 mg/L for the four-day average.

[3] The 2016 DEP CALM manual explains that a single grab sample is representative of the 1-hour average for the 860 mg/L acute chloride criterion.

7.1.2 Massachusetts (MA) Drinking Water Standards and Guidelines

MA Drinking Water Standards and Guidelines apply to treated drinking water and are defined by MA DEP in 310 CMR 22.00 and by the Massachusetts Office of Research and Standards (ORS). Created to implement the requirements of the federal Safe Drinking Water Act, these standards consist of Massachusetts Maximum Contaminant Levels (MCLs), Massachusetts Secondary Maximum Contaminant Levels (SMCLs), and Massachusetts Drinking Water Guidelines (ORS Guidelines). The MCL and SMCL standards are developed by the EPA and adopted or made more stringent by the state of Massachusetts. Parameters in drinking water delivered to customers must not exceed the MCLs. Drinking water is not required to meet SMCLs unless deemed by MA DEP or EPA to be a threat to public health. While not mandatory for compliance, ORS Guidelines can help water suppliers monitor and address pollutants of concern that are not regulated by state or federal agencies. All MCLs, SMCLs, and ORS Guidelines apply to treated drinking water rather than untreated source water. However, these metrics are useful points of comparison to assess ambient water quality and identify potential contaminants for treatment.

The CWD source water monitoring program tests ambient water for the following subset of MCL, SMCL, and ORS Guideline parameters (Table 10). CWD performs more extensive testing on treated drinking water to ensure that all required standards and guidelines are met post-treatment.

Table 10: Selected Massachusetts Drinking Water Standards and Guidelines

Category	Criteria	Type	Description
Iron (Fe) and Manganese (Mn)	0.3 mg/L, Fe 0.05 mg/L, Mn	SMCL	Iron and manganese in drinking water are not considered health hazards but an excess can lead to staining and other aesthetic issues. These metallic elements are naturally-occurring in the earth's crust and soils. Due to redox reactions, iron and manganese tend to convert from a solid to an aqueous state under low DO conditions.
Nitrate + Nitrite as Nitrogen	10 mg/L	MCL	Nitrate (NO_3^-) and nitrite (NO_2^-) are common inorganic forms of nitrogen. Typical sources of nitrate and nitrite pollution include the application of fertilizer and effluent from septic systems and other sewage discharges. The MCL is the sum of nitrate and nitrite nitrogen and was set to protect public health. The EPA nutrient criterion is more restrictive at 0.05 mg/L for reservoirs and 0.31 mg/L for tributaries but is focused on preventing eutrophication rather than protecting human health (see Section 7.1.3 *EPA Nutrient Criteria*). Nitrate nitrogen and nitrite nitrogen were measured separately by CWD and summed to quantify the total amount of nitrogen from these compounds. If the nitrate or nitrite result was below the method detection limit, the result was set to the detection limit. This erred on the side of over estimating nitrate and nitrite nitrogen concentrations in the Cambridge watershed.
Chloride	250 mg/L	SMCL	Chloride concentrations in drinking water above 250 mg/L typically correspond with sodium levels high enough to impart a noticeably "salty" taste. The chloride SMCL is set to avoid taste issues. See Table 9 for chloride chronic (230 mg/L) and acute (860 mg/L) MA Surface Water Quality Standards set to protect aquatic life.

Table 10. *Continued*			
Category	**Criteria**	**Type**	**Description**
Sodium	20 mg/L	ORS Guideline	As with chloride, the use of sodium chloride for deicing is a common source of elevated sodium in the environment. The ORS Guideline is for reporting purposes only and was set to help individuals on restricted sodium diets manage their intake (Massachusetts Department of Public Health, 2017). However, drinking water is typically not a significant source of sodium in a person's diet, with water typically accounting for less than 10 percent of an individual's sodium consumption (Massachusetts Department of Public Health, 2017]).

7.1.3 EPA Nutrient Criteria

EPA nutrient criteria represent concentrations of nutrients in lakes, reservoirs, and tributaries which have not experienced accelerated eutrophication due to anthropogenic nutrient inputs (reference conditions).[4] Nutrients facilitate plant and algal growth and promote eutrophication (water body productivity). Excessive nutrient inputs can cause increased rates of eutrophication, leading to water quality impairments including, but not limited to, taste and odor problems and low DO availability for fish and wildlife.

The EPA developed these criteria to help states adopt nutrient water quality standards to maintain the uses defined by the Clean Water Act (U.S. Environmental Protection Agency 2000, 2001). Because Massachusetts does not include numeric criteria for nutrient compounds in its Class A Surface Water Quality Standards, this report uses the nutrient criteria developed by EPA as an additional benchmark for assessing nutrient pollution in the Cambridge watershed (Table 11). CWD also compared water quality results for available parameters against indicators of nutrient enrichment as described in Section 7.1.1.

Table 11: Selected EPA nutrient criteria for ecoregion XIV, subregion 59

Category	Criteria	Description
Nitrate + Nitrite as Nitrogen	0.05 mg/L, reservoirs 0.31 mg/L, tributaries	See Table 10 for more information on nitrogen sources and the health-based MCL for treated drinking water.
Total Kjeldahl Nitrogen (TKN)	0.43 mg/L, reservoirs 0.30 mg/L, tributaries	TKN is the total of organic nitrogen and ammonia nitrogen. CWD also monitors ammonia concentrations separate from TKN.
Total Nitrogen (TN)	0.48 mg/L, reservoirs 0.61 mg/L, tributaries	TN is the sum of nitrate and nitrite nitrogen and TKN. When calculating TN, CWD set any nitrate, nitrite, and TKN results below the detection limit to the detection limit. Therefore, TN results err towards overestimating actual TN concentrations.
TP	0.008 mg/L, reservoirs	Phosphorus is believed to be the limiting nutrient for plant and algal growth in the Cambridge watershed (Waldron and Bent, 2001). Phosphorous sorbed to sediment particles can be released into the

[4] It is assumed that the 25th percentile of median nutrient concentrations in lakes, reservoirs, and tributaries monitored by EPA in the relevant subregions of Ecoregion XIV represented reference conditions (U.S. Environmental Protection Agency 2000, 2001). The Cambridge watershed is located nutrient Ecoregion XIV and subregion 59. EPA encourages states to compare local conditions to the regional nutrient criteria and to develop nutrient criteria that are specific to conditions observed at the local level.

	0.02375 mg/L, tributaries	water column under anoxic conditions, which can lead to excessive plant and algal growth, especially during the warm summer months. The TP detection limit for samples analyzed in this report was 0.0106 mg/L, greater than the 0.008 nutrient criterion for reservoirs. Therefore, CWD assumed that any sample below the detection limit was also less than the EPA nutrient criterion. TP was also used as a physico-chemical screening guideline to help identify nutrient impairment in reservoirs under the Class A standards (Table 9). However, MA DEP used the 1986 EPA Gold Book concentrations for rivers and streams, which differ from the concentrations in the EPA nutrient criteria reference conditions.
Table 11*. continued*		
Category	**Criteria**	**Description**
Secchi depth (SD)	4.9 meters, reservoirs	SD is a measure of water clarity, similar to turbidity (see below). It is quantified by lowering a Secchi disk into the water column and recording the depth at which the disk is no longer visible. CWD recorded two separate SDs during each reservoir sampling event. First, CWD recorded the SD without using an aquascope. Next, CWD recorded the SD while looking through an aquascope, a tube-shaped device that blocks glare from the water surface to help see objects underwater. Results in this report are for the non-aquascope readings. The Class A standards also use SD as an indicator of to help determine whether the Aquatic Life, Recreation, and Aesthetic uses of a water body have been met (Table 9).
Turbidity	1.68 NTU, tributaries	Turbidity is a measure of water clarity. Turbid water often has increased levels of suspended dirt and organic matter, which can have adverse effects on water quality and aquatic habitat. EPA did not present a turbidity nutrient criterion for reservoirs.

7.1.4 Other Parameters

The CWD Source Water Monitoring Program also monitors additional water quality indicators, including:

Reservoir Trophic State (TSI) - Carlson's trophic state index (TSI) is a dimensionless numerical index ranging from 0 – 100, indicating the degree of nutrient enrichment or biomass productivity of a water body (North American Lake Management Society Secchi Dip-In Program, [n.d]; Carlson, 1977). TSI values less than 40 indicate a low productivity state (oligotrophic) and optimal water quality for drinking water supplies (Table 12). Values ranging between 40 and 50 indicate moderate productivity (a mesotrophic state) and may correspond with taste and odor problems. Values greater than 50 indicate a water body that is highly productive (eutrophic), potentially from external nutrient loading, and likely to produce algal blooms.

The TSI of a water body can be estimated using chl-*a* concentrations, TP concentrations, or measured SDs. Since TSI is an estimator of algal biomass weight in the reservoir, chl-*a* is typically the optimal parameter for calculating TSI (North American Lake Management Society Secchi Dip-In Program, [n.d]; Carlson, 1977). The formula for calculating TSI using chl-*a* is as follows (North American Lake Management Society Secchi Dip-In Program, [n.d]):

$$TSI (CHL) = 9.81 \ln(\text{chl-}a\ mg/m^3) + 30.6$$

Table 12: Trophic State Index Explanation and Water Quality Implications

A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.

TSI	Chl-*a* (µg/L)	SD (m)	TP (ug/L)	Attributes	Water Supply
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.
30 - 40	0.95 - 2.6	8 - 4	6 - 12	Hypolimnia of shallower lakes may become anoxic.	
40 - 50	2.6 - 7.3	4 - 2	12 - 24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer.	Iron, manganese, taste, and odor problems worse. Raw water turbidity requires filtration.
50 - 60	7.3 - 20	2 - 1	24 - 48	Eutrophy: Anoxic hylpolimnia, macrophyte problems possible.	
60 -70	20 - 56	0.5 - 1	48 - 96	Blue-green algae dominate, algal scums and macrophyte problems.	Episodes of severe taste and odor possible.
70 - 80	56 - 155	0.25 - 0.5	96 - 192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes.	
>80	>155	<0.25	192 - 384	Algal scums, few macrophytes.	
Table source: North American Lake Management Society Secchi Dip-In Program, [n.d]					

<u>Specific Conductance (SpC)</u> – Specific conductance is the ability of water to conduct electrical current, normalized to 25°C. In the field, it is used as a surrogate for sodium and calcium chloride deicing agents. Abrupt changes in specific conductance can also be an indicator of pumping, dumping or other activities requiring investigation.

<u>Total Organic Carbon (TOC)</u> – TOC is used to quantify naturally-occurring organic matter in the water supply. When mixed with chlorine, carbon can react to form disinfection byproducts (haloacetic acids and trihalomethanes) regulated by Massachusetts Drinking Water Standards and monitored by CWD during the treatment and water distribution processes.

8 RESERVOIR WATER QUALITY

Analysis of water quality during the 2018 calendar year at Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs aimed to answer the following questions:

- Did reservoir waters have high concentrations of metals and nutrients associated with taste, odor, aesthetic, or public health problems in treated drinking water?
- How did water quality in 2018 compare against the USGS 1997-1998 baseline and other historic data?
- Were reservoir waters of high enough quality to adequately support aquatic life?
- Although not permitted in drinking water supplies, was reservoir water quality safe for primary contact recreation?
- Did water quality in the Cambridge reservoir allow for pleasing aesthetics?

To answer these questions, CWD compared results against the Class A water quality standards, MCL and SMCLs, ORS Guidelines, and EPA nutrient criteria. CWD also compared water quality results against data collected by the USGS during a 1997-1998 baseline assessment and data collected by CWD since 2000.

8.1 PH

8.1.1 pH Overview

To protect aquatic life, the Class A water quality standards require pH to remain between 6.5 and 8.3 unless naturally occurring. CWD measured pH in the field (*in situ)* with a water quality probe as well as in the CWD laboratory (lab) by using water quality probes to measure the pH in water samples.

8.1.2 pH Results

In 2018, all *in situ* and laboratory pH readings from Fresh Pond Reservoir were within the acceptable Class A range according the MA Surface Water Quality Standards (Figure 8 and Table 13). The 2018 *in situ* pH measurements at Hobbs Brook Reservoir were also within the 6.5 to 8.3 Class A range (Figure 9 and Table 13). One HB @ Intake weekly sample collected on August 2nd and analyzed in the CWD lab was greater than the 8.3 Class A upper bound (8.37) (Table 13). However, the DEP CALM guidance manual explains that the Aquatic Life use is met if there are "no or slight excursions (<0.5 SU)" from the criteria. Because 8.37 is less than 0.5 SU from 8.3, and it only occurred in one out of 51 samples, elevated pH was not a water quality concern at Hobbs Brook Reservoir.

pH in the first 2 meters of the Stony Brook Reservoir August 8th profiles were more extremely elevated, ranging from 8.69 to 8.86, and greater than 0.5 SU above the 8.3 upper bound (Figure 10). The SB @ DH pH measured in the CWD lab on August 8th was similarly elevated at 8.98. In addition, the weekly SB @ Intake water quality sample collected the next day on August 9th was 8.92, followed by a slightly elevated pH of 8.64 the subsequent week on August 16th.

Table 13: Reservoir pH statistics measured in situ and in the CWD laboratory, 2018

Basin Name	Site Name	pH Type	n <6.5 or >8.3	n	%	Min	Max	Median	Mean
Hobbs Brook	HB @ Upper	lab	1	6	17	**6.20**	7.52	6.73	6.87
		in situ	0	6	0	7.09	8.03	7.52	7.54
	HB @ Middle	lab	0	6	0	6.55	7.55	6.82	6.97
		in situ	0	6	0	7.10	7.69	7.45	7.44
	HB @ DH	lab	0	6	0	7.22	7.74	7.51	7.48
		in situ	0	6	0	7.32	7.53	7.45	7.44
	HB @ Intake	lab	1	51	2	6.72	**8.37**	7.38	7.38
		in situ	0	6	0	7.05	7.48	7.30	7.29
Stony Brook	SB @ DH	lab	1	6	17	7.08	**8.98**	7.49	7.68
		in situ	1	6	17	7.31	**8.69**	7.65	7.78
	SB @ Intake	lab	3	51	6	**6.42**	**8.92**	7.23	7.33
		in situ	1	6	17	7.20	**8.81**	7.31	7.58
Fresh Pond	FP @ Cove	lab	0	1	0	7.37	7.37	7.37	7.37
		in situ	0	9	0	7.16	7.85	7.28	7.40
	FP @ DH	lab	0	7	0	7.03	7.51	7.37	7.36
		in situ	0	9	0	7.39	8.24	7.57	7.66
	FP @ Intake	*in situ*	0	9	0	7.20	7.75	7.34	7.39

n = number of samples, n <6.5 or >8.3 = number of samples outside Class A pH bounds, % = percent of samples outside the Class A pH bounds, min = minimum pH, max = maximum pH, bolded pH statistics are outside the Class A pH bounds

The extreme pH elevation at Stony Brook Reservoir during August (>0.5 SU above 8.3) occurred during and immediately after a heatwave. Air temperatures were above 90 degrees F on August 2nd and August 5th-8th with corresponding water temperatures above the 28.3 degrees C Class A warm water fishery standard (Figure 10 and Figure 13; see Section 8.2 *Temperature*). The warm temperatures may have led to increased primary production, thereby reducing carbon dioxide concentrations in the water during photosynthesis resulting in elevated pH. However, the chl-*a* result from the August 8th surface water quality sample at SB @ DH was only 5.92 mg/m^3, which corresponds to a TSI of 48 and mid-level productivity in the mesotrophic range (see Section 8.6 *Eutrophication).*

Except for a low pH of 6.42 measured in the CWD lab for SB @ Intake on February 22nd, all 2018 pH readings outside the Class A bounds at Stony Brook Reservoir were elevated and occurred during or just after the August heatwave (Figure 10 and Table 13). Still, exceedances at Stony Brook Reservoir amounted to only 6 percent of weekly SB @ Intake samples analyzed in the CWD lab and 17 percent (1 of 6 samples) at SB @ DH (Table 13). Historically, exceedances of the 8.3 pH Class A upper bound are rare at Stony Brook Reservoir and all Cambridge reservoirs (Figure 11). Of surface samples collected by CWD between 2000 and 2018, only SB @ DH had a 90th percentile pH above 8.3 during the month of August and the median pH levels for all reservoir surface sites in all months were below 8.3 (Figure 11). If the August heatwave caused the elevated pH in 2018, then more instances of elevated pH could occur in the future due to climate change. However, for the time being, elevated pH is not currently a water quality concern in Cambridge's reservoirs.

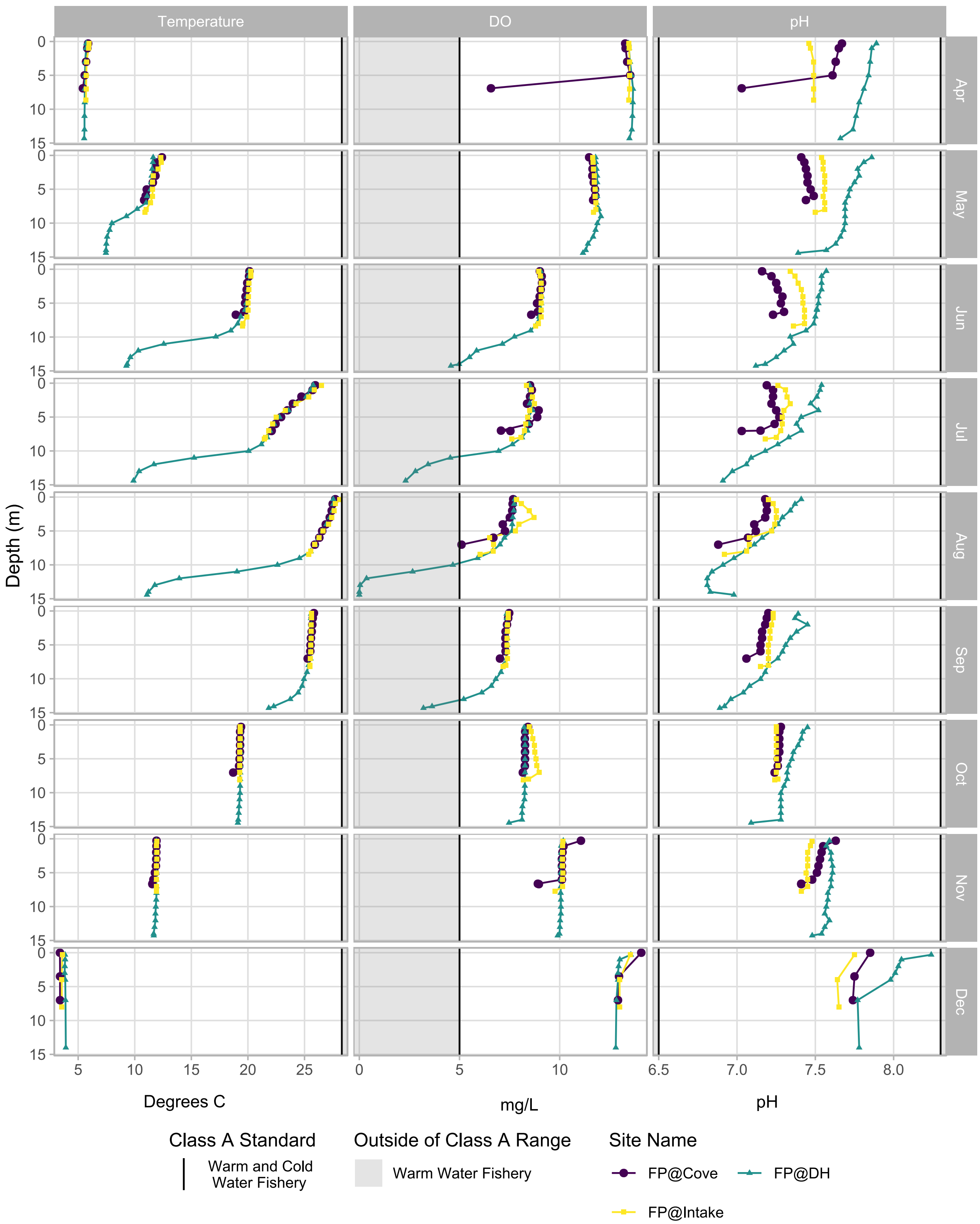


Figure 8: Fresh Pond Reservoir 2018 Temperature, Dissolved Oxygen (DO), and pH

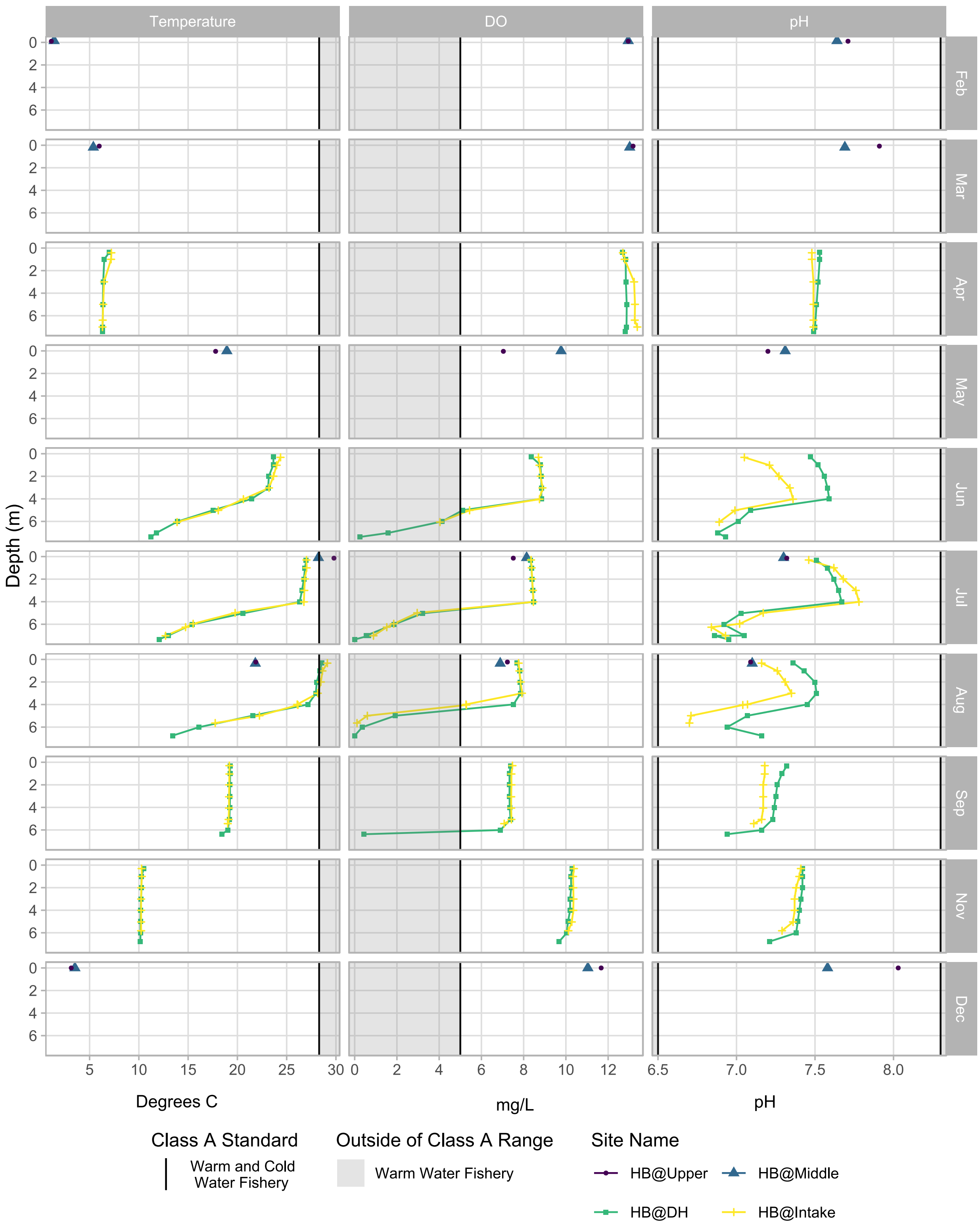


Figure 9: Hobbs Brook Reservoir 2018 Temperature, Dissolved Oxygen (DO), and pH

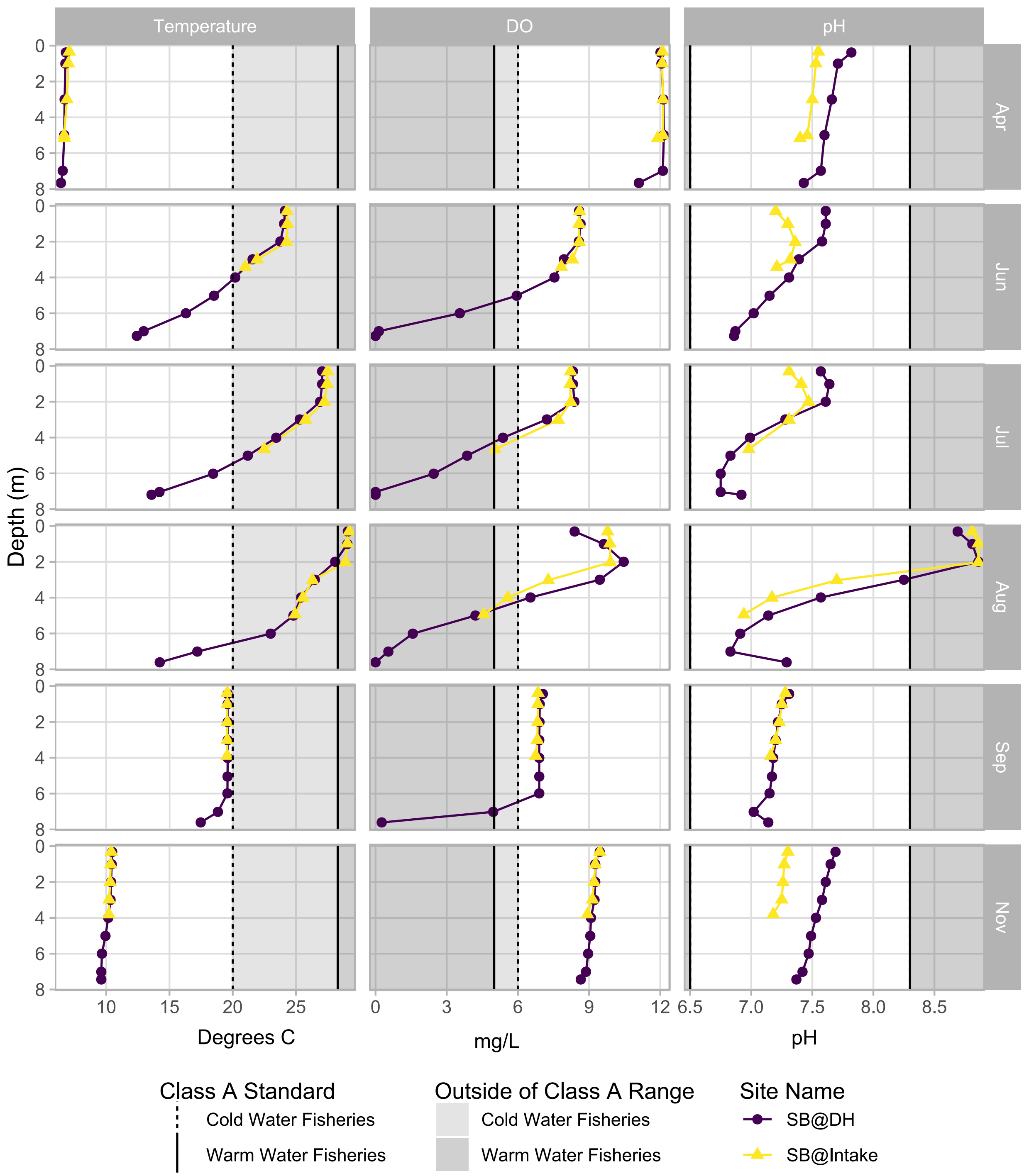


Figure 10: Stony Brook Reservoir 2018 Temperature, Dissolved Oxygen (DO), and pH

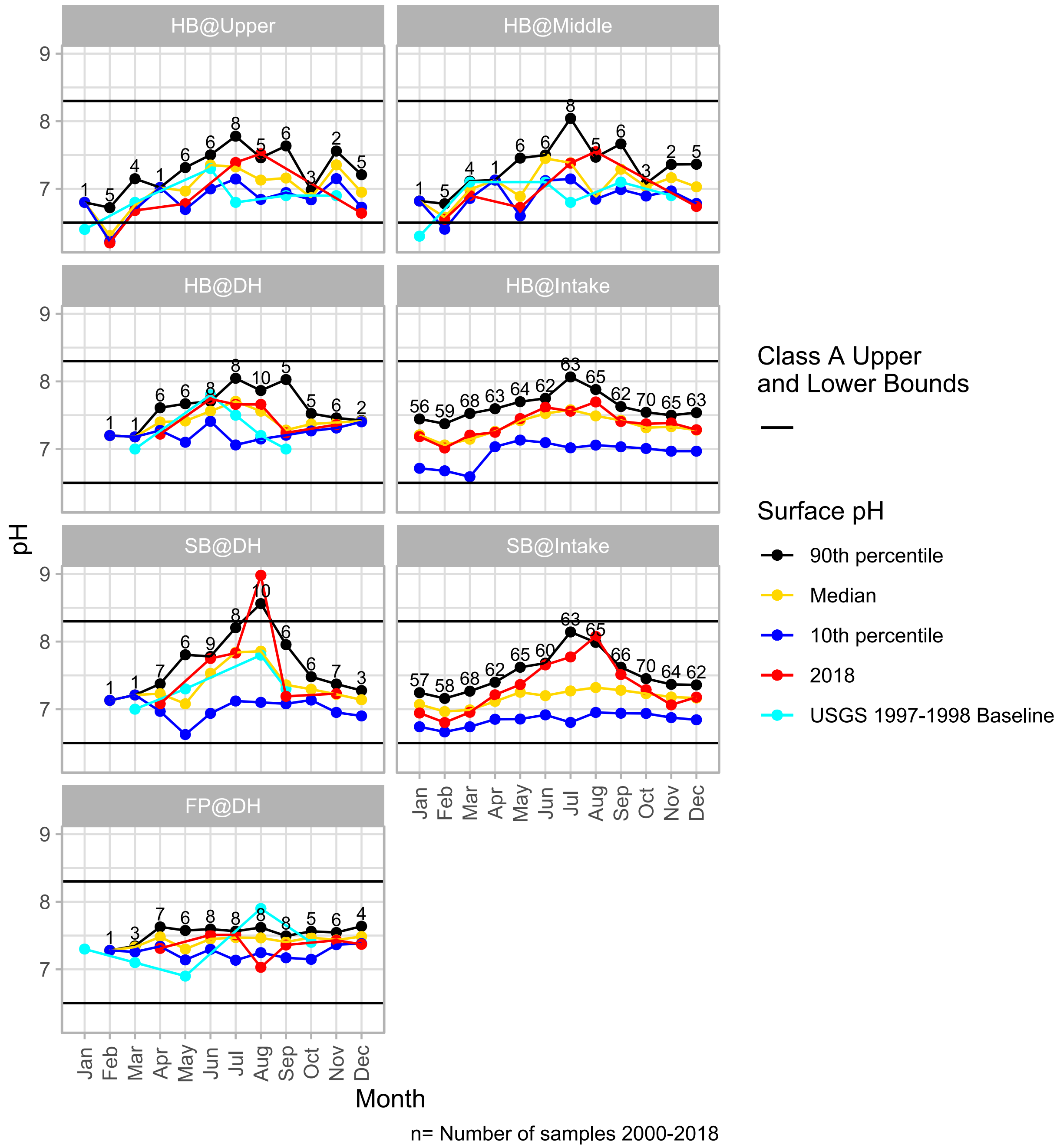


Figure 11: Reservoir pH statistics from 2000-2018 and USGS 1997-1998 baseline pH

8.2 TEMPERATURE

8.2.1 Overview

To protect aquatic life, the Class A water quality standard requires that warm water fish habitat temperatures not exceed 28.3 degrees C. The CFR standard is more stringent, setting the 7-day average daily maximum temperature (7-DADM) at 20 degrees C unless naturally occurring.

Because water is most dense at four degrees C, seasonal changes in temperature can cause thermal stratification in reservoirs as follows:

- Spring: Surface water begins to warm, forming a distinct upper layer (epilimnion) of less dense water that will not mix with colder, denser bottom waters (hypolimnion).

- Summer: Separated from oxygen-rich waters in the epilimnion, aerobic respiration in the hypolimnion can deplete the DO, resulting in reduced (low DO) conditions that stress fish and other aquatic fauna. Nuisance metals, such as iron and manganese, and phosphorus bound to sediments, can be released into the hypolimnion in the absence of oxygen.

- Fall: Surface water begins to cool, eventually becoming the same temperature as the hypolimnion. This allows the water column to mix and re-oxygenate the bottom of the reservoir. The metals and nutrients released during the summer in the hypolimnion are mixed throughout the water column during this fall "turn over" event.

- Winter: Some reservoirs stratify again during the winter, with warm, denser water (4 degrees C) at the bottom of the reservoir and cooler, less dense water and ice (0 degrees C) at the surface. In this case, a mixing event occurs in the spring as well as the fall.

CWD reservoirs typically undergo summer stratification and fall mixing. CWD reservoirs may also stratify in the winter and mix in the spring. However, winter conditions often prevent CWD from collecting water quality profiles during this time of year, making it difficult to capture potential winter stratification and spring mixing.

8.2.2 Temperature Results

Profiles from 2018 show that all three reservoirs stratified thermally by June (Figure 8, Figure 9, Figure 10). Thermal stratification at Fresh Pond began earlier, with the a distinct epilimnion, thermocline, and hypolimnion evident in the May profile at the FP @ DH site (Figure 8). It is possible that Hobbs Brook and Stony Brook Reservoirs also stratified before June. However, profiles were not collected at Hobbs Brook and Stony Brook Reservoirs during May.

In a typical year, water temperatures at Hobbs Brook, Stony Brook, and Fresh Pond reservoirs remain below the 28.3 degrees C Class A standard for warm water fisheries (Figure 12). For example, median monthly surface temperatures for all reservoir sites monitored by CWD between 2000 and 2018 were below 28.3 degrees C as were all measurements collected during the USGS 1997-1998 baseline study. In addition, the 90th percentiles of the monthly surface temperatures measured by CWD since 2000 were less than 28.3 degrees C except at HB @ Upper, where the 90th percentile of July temperatures was 28.8 degrees C (Figure 12 and Table 14).

However, summer water temperatures in 2018 were warmer than usual. Water temperature during the July 5th sampling event at HB @ Upper exceeded the Class A temperature standard of 28.3 degrees C and was also nearly a degree warmer than the 90th percentile for July (29.8 degrees C versus 29.0 degrees C) (Figure 9 and Figure 12; Table 14). Although no other reservoir site measured by CWD exceeded the Class A warm water fishery standard in July of 2018, continuous USGS probe readings at Fresh Pond Reservoir showed that water temperatures exceeded 28.3 degrees C on July 5, the same date that CWD measured an exceedance at HB @ Upper (Table 15). In addition, the July 2018 surface temperatures measured by CWD at HB @ Middle and FP @ DH were among the warmest 10 percent of temperatures during that month from 2000 through 2018 (Figure 12).

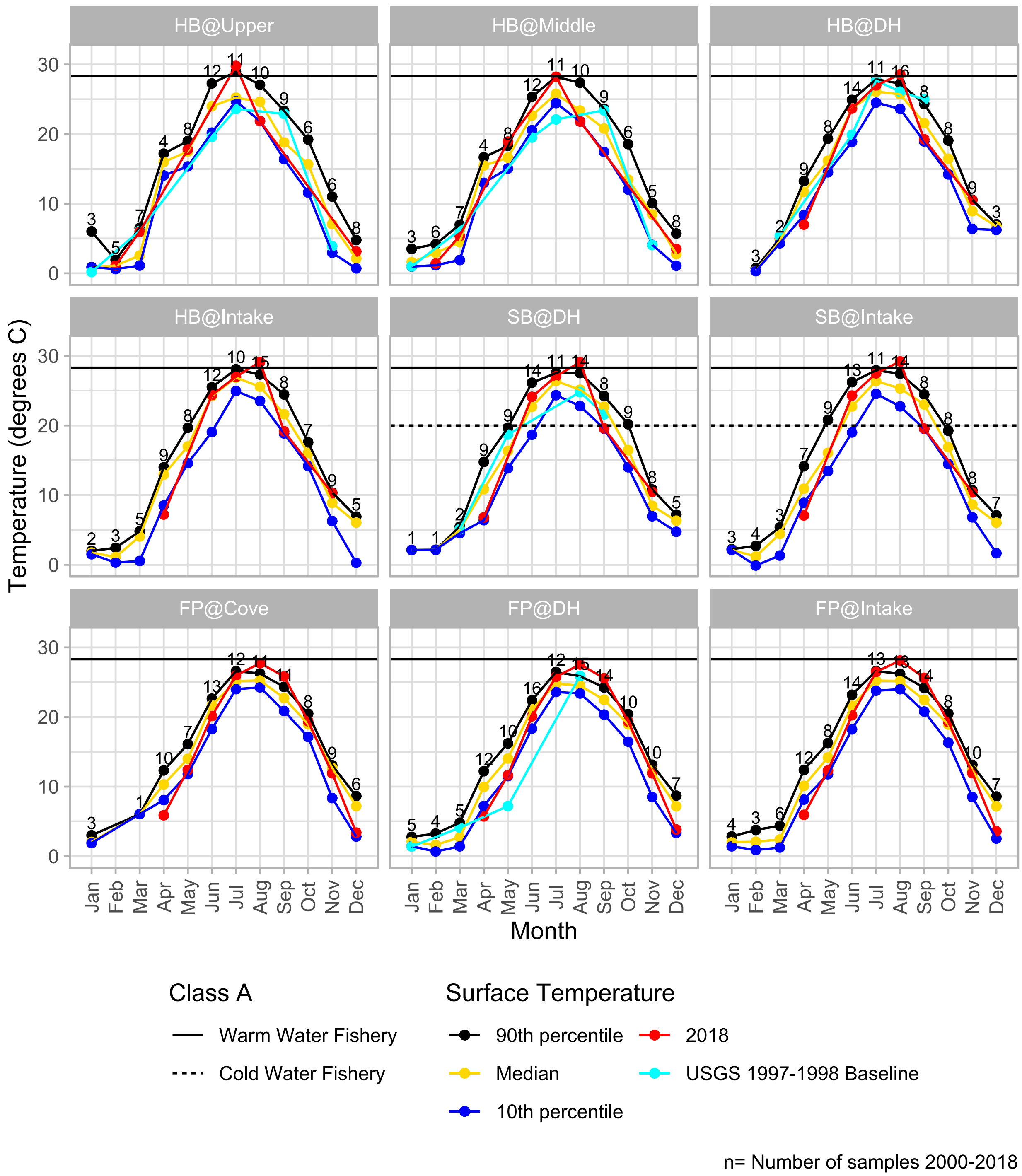


Figure 12: Reservoir surface temperatures measured by CWD from 2000 - 2018 and 1997-1998 USGS baseline temperatures

Table 14: Comparison of July – September reservoir surface temperatures to the 2000-2018 CWD data set and the 1997-1998 USGS baseline measurements

	Temperature (Degrees C)								
	July			August			Sept		
Site Name	**2018**	**90th**	**USGS**	**2018**	**90th**	**USGS**	**2018**	**90th**	**USGS**
HB @ Upper	**29.8**	**29.0**	23.6	21.9	27.1	--	--	23.3	--
HB @ Middle	28.2	28.2	22.1	21.8	27.4	--	--	23.6	--
HB @ DH	27.0	27.9	27.7	**28.6**	27.3	26.1	19.3	24.3	25.0
HB @ Intake	27.0	28.1	--	**29.1**	27.3	--	19.2	24.5	--
SB @ DH	27.1	27.5	--	**29.1**	27.5	24.8	19.6	24.3	21.6
SB @ Intake	27.5	27.9	--	**29.2**	27.4	--	19.6	24.5	--
FP @ Cove	26.0	26.6	--	27.7	26.3	--	25.8	24.3	--
FP @ DH	25.8	26.5	--	27.5	25.9	25.9	25.6	24.2	--
FP @ Intake	26.5	26.6	--	28.1	26.2	--	25.6	24.2	--

90th= 90th percentile of temperature measurements collected by CWD from 2000 through 2018
USGS = temperature measured by the USGS during the USGS 1997-1998 baseline study
-- = no data
Bolded temperatures exceeded the Class A 28.3 degree C warm water fisheries temperature standard
Underlined 2018 temperatures exceeded the 1997-1998 USGS baseline temperature

Table 15: Class A Hobbs Brook Reservoir and Fresh Pond Reservoir water temperature exceedances in 2018, USGS Data

Site	USGS station ID	# Days, max temp > 28.3 degrees C	Dates, max temp > 28.3 degrees C	Max Temp
HB @ Middle	01104425	0	none	27.7
HB @ Intake	01104430	3	Aug 9-11	28.8
FP @ Intake	422302071083801	6	July 5, Aug 6-10	29.3

Data source = approved and provisional data from USGS continuous monitoring stations. Accessed from NWIS website 5/20/2019. Max temp = maximum temperature

The unusually warm water conditions continued into August. The August 8th profiles from the Hobbs Brook lower basin (HB @ DH and HB @ Intake) and Stony Brook Reservoir (SB @ DH and SB @ Intake) sites exceeded the warm water fishery Class A standard in the first 2 to 3 meters of the water column (Figure 9 and Figure 10). The exceedances measured by CWD at HB @ Intake agreed with continuous USGS temperature data, which showed maximum daily water temperatures above 28.3 degrees C from August 9-11 (Table 15). The continuous USGS data also indicated that the daily maximum water temperature at FP @ Intake exceeded 28.3 degrees C from August 6 -10 (Table 15). No continuous USGS temperature data were collected at Stony Brook Reservoir.

In addition to exceeding the Class A warm water fisheries temperature standard, August surface waters measured by CWD in the Hobbs Brook Reservoir lower basin, Stony Brook Reservoir, and Fresh Pond Reservoir were warmer than the 90th percentile of temperatures for the month (Table 14 and Figure 12). The deep hole sites at all three reservoirs also exceeded the August surface temperatures recorded during the 1997-1998 USGS baseline study (Table 14 and Figure 12).

Interestingly, August surface temperatures at HB @ Upper and HB @ Middle measured by CWD were lower than the 90th percentiles and the 28.3 degrees C Class A standard. This could be due to the timing of the measurement, which occurred towards the end of the month on August 30th when air temperatures were temporarily cooler before rising again the during the first week in September (Figure 13).

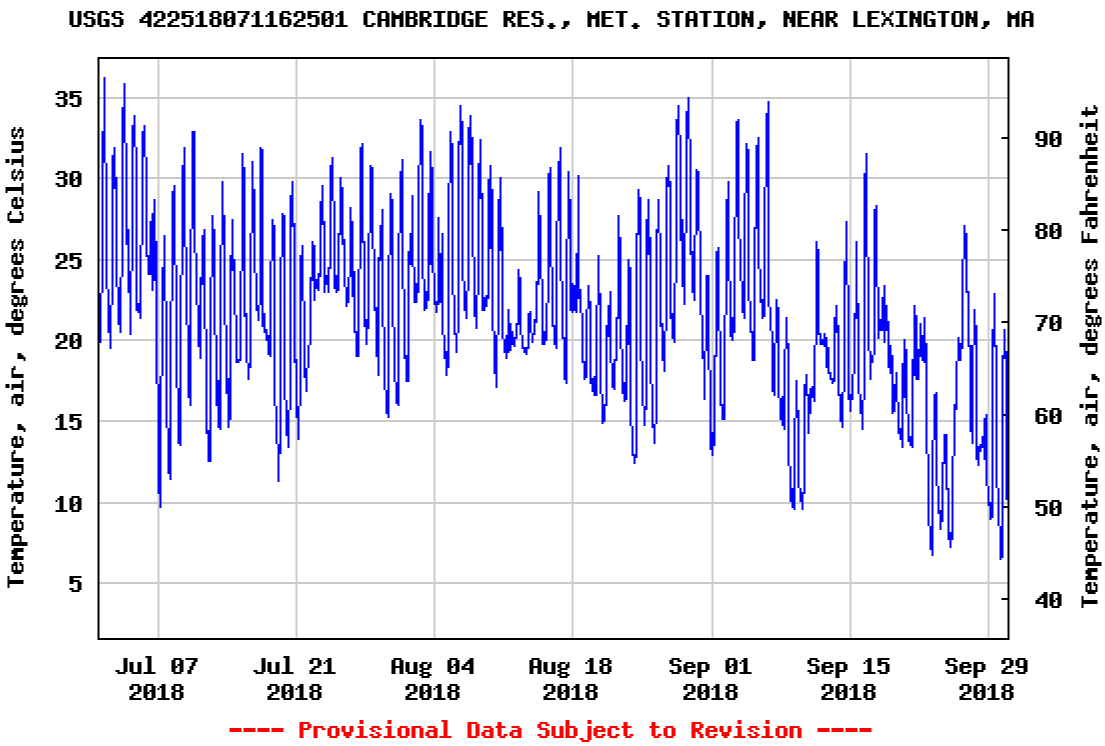


Figure 13: Air Temperature from USGS Station 422518071162501 near Lexington, MA, July - September 2018

By September, temperatures at all reservoirs had dropped to below 28.3 degrees C, no longer exceeding the Class A warm water fishery standard (Figure 8, Figure 9, Figure 10). However, Fresh Pond surface temperatures recorded by CWD during the September 5th profile were above the 2000 – 2018 90th percentile (Figure 12). This is likely because air temperatures were still quite warm at the beginning of September, exceeding 90 degrees F on September 3rd and 5th (Figure 13). The Hobbs Brook and Stony Brook reservoir profiles were collected later in the month on September 25th, after temperatures had dropped leading into fall.

Despite being an impoundment, the Stony Brook Reservoir is classified as a CFR by the Massachusetts Division of Fisheries and Wildlife. Therefore, Stony Brook Reservoir water temperatures were also compared against the 20 degrees C CFR standard for the 7-DADM temperature. In addition to exceeding the 28.3 degree warm water fish standard in the top 2 meters of the water column in August, Stony Brook Reservoir also exceeded 20 degrees C during June, July, and August (Figure 10).[5] The depth of the water column above 20 degrees C ranged from approximately 4 meters in June, increasing to between 6 and 7 meters in depth by August. While exceedances of the warm water fish standard are rare, Stony Brook

[5]Continuous temperature data were not collected at Stony Brook Reservoir. According to the 2016 CALM manual, small datasets with only instantaneous measurements should never exceed, or only rarely exceed, the 20 degrees C Class A standard. However, a dataset containing only infrequent discrete/instantaneous measurements would not be sufficient to classify a waterbody as impaired.

Reservoir frequently exceeds 20 degrees C in the summer months (Figure 12).

The atypically warm water temperatures in 2018, especially in August, were likely attributable to warmer than normal air temperatures. The 2018 average daily and maximum daily air temperatures in July, August, and September 2018 were higher than, but within 1 to 2 standard deviations of, the monthly mean and mean daily maximum normal temperatures for 1981 – 2010 (Table 16). Strikingly, the number of days at or above 90 degrees F in August was almost double normal (7 days versus the normal of 3.8) occurring on August 2, 5 – 8, and 28 – 29. September had three days above 90 degrees: September 3, 5, and 6. This was more than triple the number of days at or above 90 degrees compared to normal. All exceedances of the 28.3 degrees C Class A warm water fishery standard measured by CWD and USGS occurred during periods with air temperatures above 90 degrees F.

Table 16: Comparison of 2018 air temperatures (degrees F) in the Cambridge watershed to 1981-2010 climate normals for Bedford Hanscom Field

	June		July		August		September	
Temperature Statistic	**2018**	**Normal**	**2018**	**Normal**	**2018**	**Normal**	**2018**	**Normal**
Mean	65.9	67.0	74.4	72.9	74.5	71.2	65.9	62.5
Average Daily Max	77.2	77.2	86.1	83.7	84.3	81.5	74.9	73.0
# days ≥ 90 degrees F	1.0	1.6	5.0	5.1	7.0	3.8	3.0	0.7

1981-2010 Normal data for Bedford Hanscom Field https://www.ncdc.noaa.gov/cdo-web/datatools/normals
Average standard deviation for normal monthly means ranged from 2.0-2.1 and 2.2-2.7 for average daily maximum temperatures; max = maximum
2018 data from USGS met station 422518071162501

While further study is needed, 2018 data indicate that 90-degree F air temperature, particularly during consecutive days, may be a tipping point that can increase Cambridge reservoir water temperatures above 28.3 degrees C. If warmer than normal summers with become more frequent, perhaps due to climate change, aquatic life in the Cambridge reservoirs may be impaired as a result. Warmer temperatures may also contribute to increased biological activity and place the reservoir at risk of algae blooms, a currently uncommon occurrence in the Cambridge reservoirs. For example, in 2018, a 1.5-inch rainstorm occurred on June 28th and was followed by five days with maximum temperatures above 88 degrees F, three of which were above 90 degrees F (Figure 13). The rainstorm resulted in a flux of sediment (and presumably nutrients) entering the Hobbs Brook Reservoir due to a failure in erosion control from a nearby construction site. On July 2, 2018, CWD observed a small algae bloom that lasted less than a week (Figure 14). While the bloom was short lived and did not occur in the downstream reservoirs, it serves as a reminder that warm weather combined with nutrient influxes can cause water quality and aesthetic problems in the reservoirs.

Figure 14: Algae bloom observed in Hobbs Brook Reservoir along Winter Street in Waltham, MA on July 2, 2018

8.3 DISSOLVED OXYGEN (DO)

8.3.1 DO Overview

To protect aquatic life, the Class A water quality standards mandate that DO in warm water fisheries remain at or above 5 mg/L. The CFR Class A standard is more stringent, requiring concentrations of 6 mg/L or greater. By contrast, waters supersaturated with DO suggest high rates of photosynthesis, an indicator of primary productivity that could signify an algae bloom.

In the absence of oxygen, decomposition of organic matter through anaerobic respiration can lead to the release of nuisance metals such as iron and manganese from the reservoir sediments. Further, phosphorous sorbed to solid iron compounds when DO is plentiful releases into the water column when iron switches from a solid to aqueous state under anaerobic conditions. This phosphorus may then contribute to unwanted biological activity in the reservoir, such as algae and nuisance plant growth. This report defines hypoxic and anoxic conditions as DO below 2 mg/L and 0.5 mg/L, respectively (Rounds and others, 2013).

8.3.2 DO Results

Because warm water holds less DO than cold water, surface water DO concentrations were highest when the water temperature was lowest in the spring and fall (Figure 8, Figure 9, Figure 10). Although surface DO concentrations measured by CWD dropped as temperatures warmed in the summer months, surface DO concentrations at all reservoir sites in 2018 remained above both the 5 mg/L and 6 mg/L Class A DO standards (Figure 8, Figure 9, Figure 10). Provisional USGS DO data from a probe submerged mid-depth at the Winter Street Gatehouse indicated that DO was below 5 mg/L from June 16th through July 19th in 2018, although data were missing from July 19th through July 31st (Figure 15). The minimum daily DO concentration measured by the USGS was also less than 5 mg/L on August 2 in 2018.

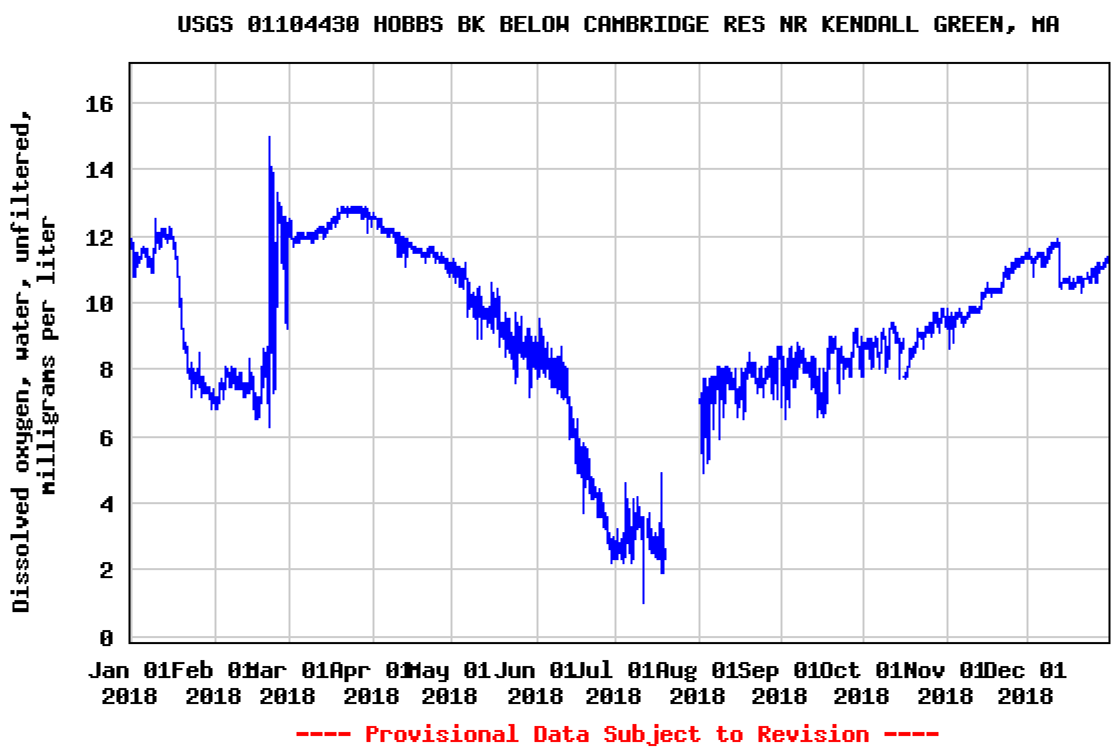


Figure 15: USGS Provisional DO data from station 01104430 near HB @ Intake, 2018

DO concentrations measured by CWD were below the 5 and 6 mg/L Class A thresholds in the hypolimnion of all three reservoirs during the period of thermal stratification between June and September (Figure 8, Figure 9, Figure 10; Table 17). Water in the Hobbs Brook and Stony Brook reservoirs fell below the Class A standard for warm water fisheries at similar points in the water column (4 to 7 meters in depth, depending on the month).

Table 17: Depth in reservoir water column where DO fell below the Class A, hypoxic, and anoxic thresholds during thermal stratification

	DO Depletion Starting Depth (m)								
	< Class A standard			Hypoxic			Anoxic		
Month	**HB**	**SB**	**FP**	**HB**	**SB**	**FP**	**HB**	**SB**	**FP**
June	5-6	5-6 (4-5)	13-14	6-7	6-7	--	7-7.4	6-7	--
July	4-5	4-5 (3-4)	10-11	5-6	6-7	--	7-7.4	6-7	--
Aug	4-5	4-5 (4-5)	9-10	4-5	5-6	11-12	5-6	7-7.6	11-12
Sept	6-6.4	6-7 (6-7)	13-14	6-6.4	7-7.6	--	6-6.4	7-7.6	--

HB = Hobbs Brook Reservoir, SB=Stony Brook Reservoir, FP = Fresh Pond Reservoir
-- = DO > threshold at all depths of the water column
Class A standard = 5 mg/L for warm water fisheries and 6 mg/L for CFRs
Depths in () are the starting depth ranges where DO first dropped below the 6 mg/L CFR standard at SB
Hypoxic < 2 mg/L DO, Anoxic < 0.5 mg/L DO (Rounds and others, 2013)

Fresh Pond Reservoir is deeper (approximately 15 meters at the deep hole site) than Hobbs Brook and Stony Brook reservoirs (deep hole depths of 7- 8 meters) (Figure 8, Figure 9, Figure 10). Fresh Pond also has a continuously operated aeration system that supplied oxygen to the bottom of Fresh Pond during 2018. While the aeration system was unable to prevent DO levels from dropping below 5 mg/L in the hypolimnion during 2018, oxygen depletion at Fresh Pond was less severe than at Hobbs Brook and Stony Brook reservoirs (Figure 8, Figure 9, Figure 10; Table 17). For example, DO at Fresh Pond did not fall below 5 mg/L until 9 to 14 meters in depth during summer stratification. By contrast, DO concentrations at Hobbs Brook and Stony Brook reservoirs were less than 5 mg/L after only 4 to 7 meters in depth during the same timeframe.

8.3.2.1 DO and Release of Iron, Mn, and TP

In addition to stressing aquatic life, extreme DO depletion can lead to anaerobic respiration and the release of iron, manganese, and TP from reservoir sediments. While both Hobbs Brook and Stony Brook reservoirs experienced hypoxic (<2 mg/L) and anoxic conditions (<0.5 mg/L) in the lowest depths of the water column from June through September, Fresh Pond only experienced hypoxia and anoxia during the month of August at depths below 11-12 meters (Figure 8, Figure 9, Figure 10; Table 17). The aeration system likely limited the extent and duration of hypoxic and anoxic conditions at Fresh Pond.

The more extreme oxygen depletion in the hypolimnion at Hobbs Brook and Stony Brook reservoirs coincided with higher concentrations of iron and manganese (Figure 16). Bottom concentrations of manganese at Hobbs Brook and Stony Brook reservoirs ranged from 1.0 to 11.4 mg/L and were orders of magnitude greater than the 0.05 mg/L SMCL, a criterion set for treated drinking water to avoid taste and odor issues. At Fresh Pond, which had more DO in the hypolimnion than at Hobbs Brook and Stony Brook, bottom concentrations ranged from 0.13 mg/L to 3.2 mg/L. These concentrations were still above the

SMCL but less than at Hobbs Brook and Stony Brook reservoirs. Iron concentrations from the anoxic hypolimnions at HB @ DH and SB @ DH ranged from 0.8 mg/L to 11.7 mg/L and were well above the taste and odor SMCL. Fresh Pond samples from both the surface and bottom of the reservoir were below the 0.3 mg/L iron SMCL.

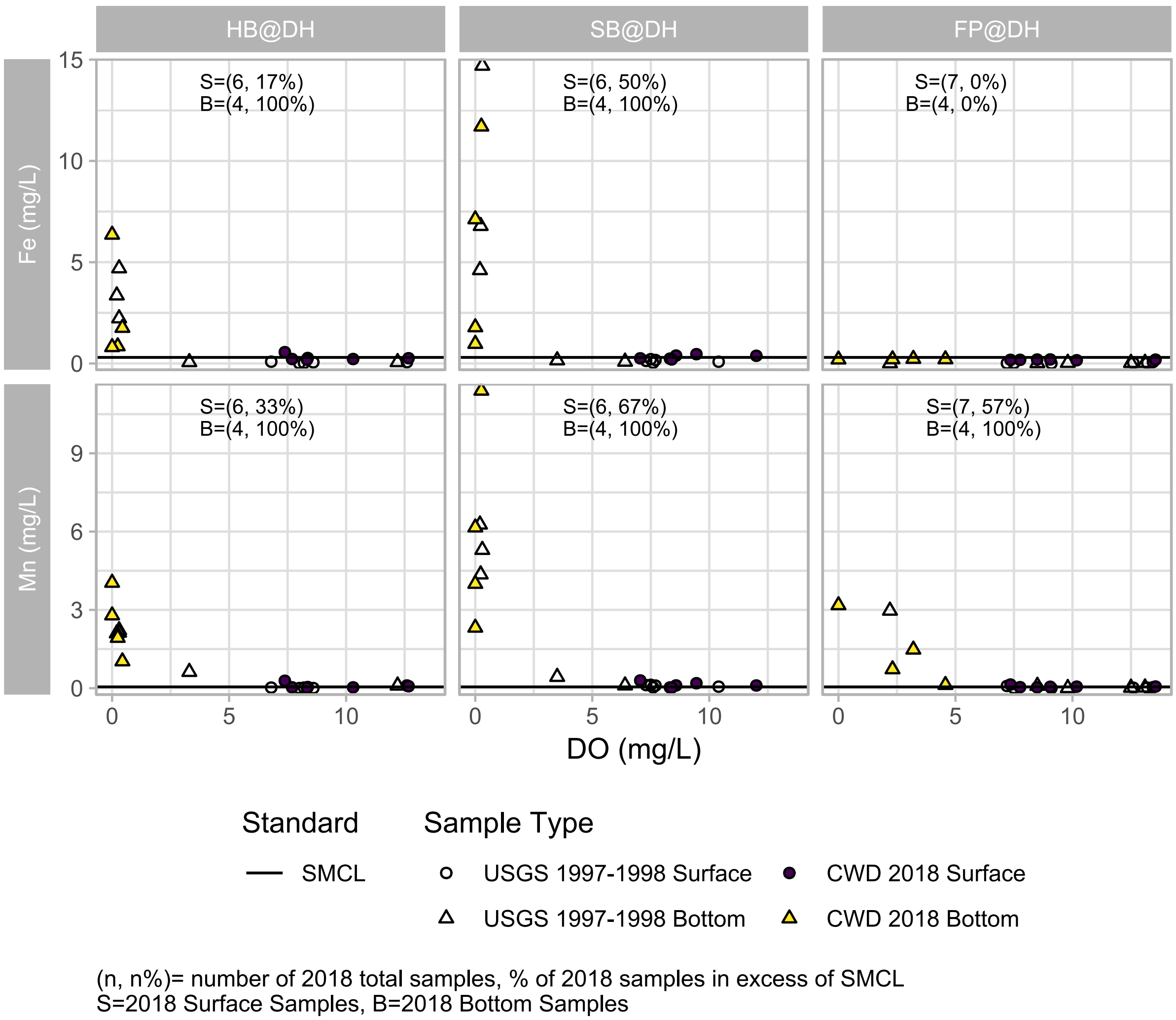


Figure 16: Dissolved Oxygen (DO) compared against iron and manganese at Hobbs Brook, Stony Brook, and Fresh Pond Reservoir deep hole sampling sites, USGS 1997-1998 baseline study and 2018

Because manganese is more energetically favorable than iron for anaerobic respiration, it was unsurprising that manganese concentrations increased at Fresh Pond during low DO conditions. However, the fact that iron concentrations remained low under anoxic and hypoxic conditions suggests that the aeration system provided enough oxygen to prevent iron reduction during anaerobic respiration. The pattern of elevated manganese and iron under hypoxic and anoxic conditions at Hobbs Brook and Stony Brook Reservoirs in bottom samples, and elevated manganese in Fresh Pond bottom samples, is not new; data from the USGS 1997-1998 baseline study showed a similar pattern between DO and iron and manganese (Figure 16).

Internal TP loading can occur from phosphorous sorbed to iron compounds when iron is released under anerobic conditions. Low TP concentrations at the surface and bottom of FP @ DH corresponded with low iron concentrations in 2018 (Figure 17). TP concentrations in bottom samples with elevated iron were generally higher than in surface samples with lower iron concentrations (Figure 17). However, other factors and sources of TP, such as decomposing organic matter and algae, likely also influenced TP concentrations in the reservoirs.

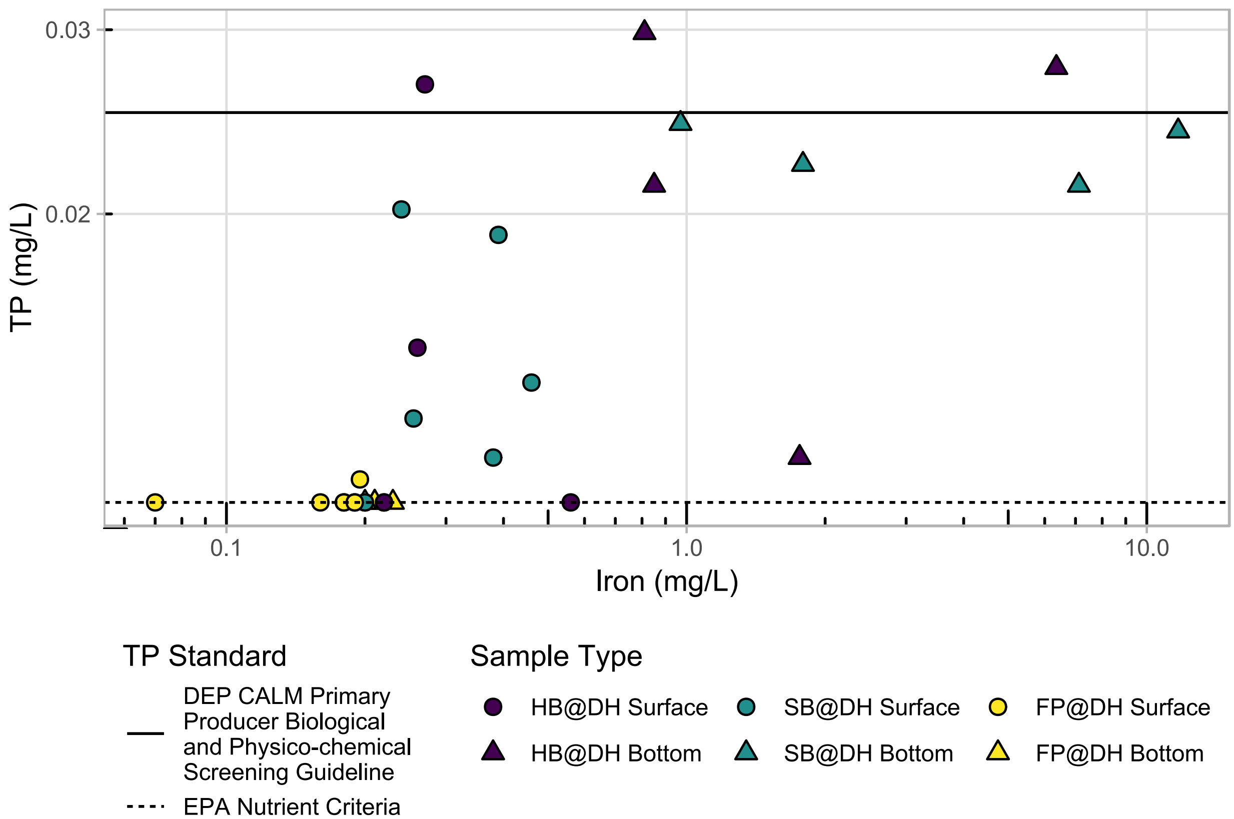
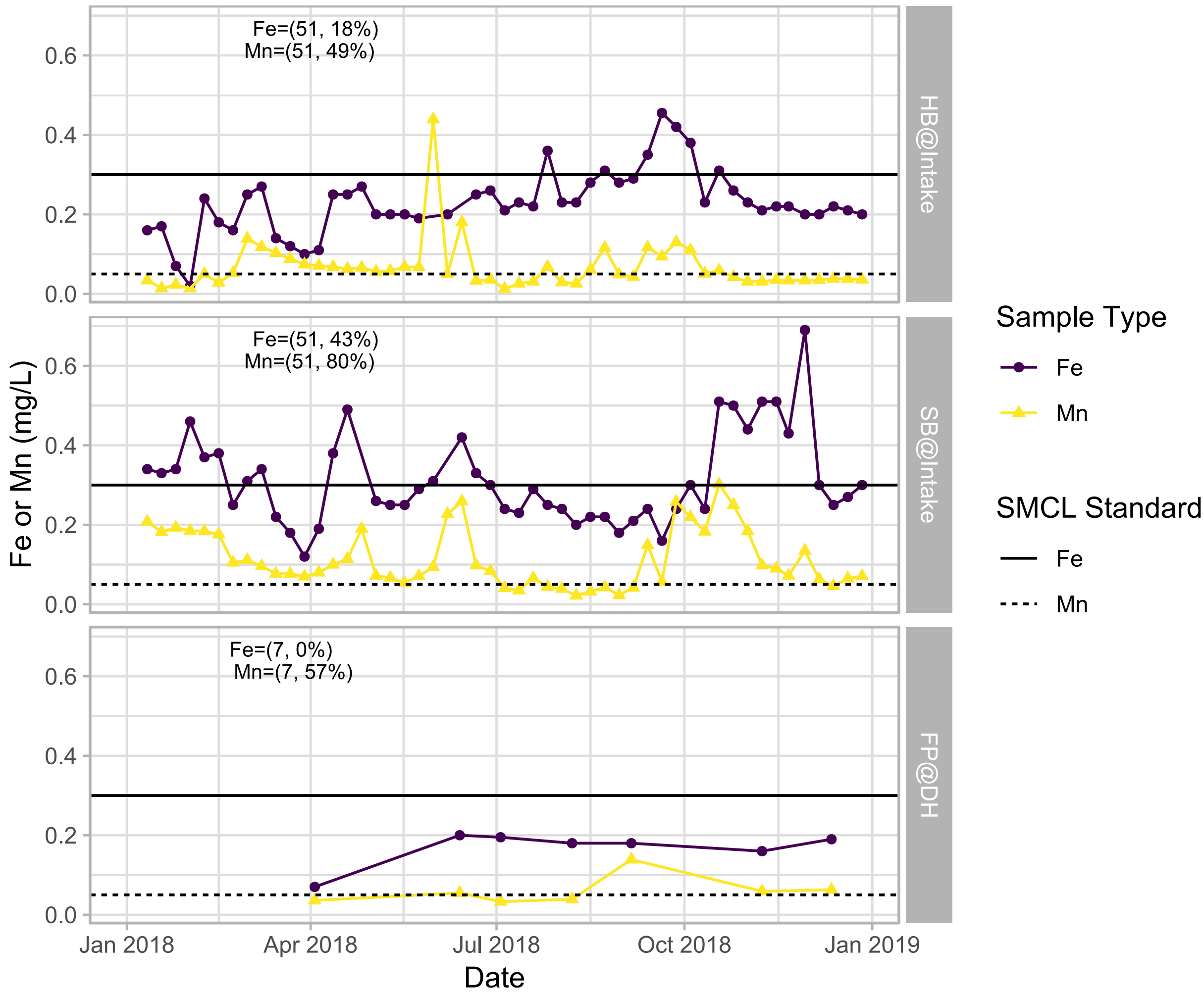


Figure 17: Comparison of iron and TP concentrations at the reservoir deep hole surface and bottom sampling locations, 2018

8.4 Iron and Manganese

8.4.1 2018 Iron and Manganese Results

As shown in Figure 18, surface concentrations of iron and manganese from weekly samples at HB @ Intake rose between September and October before tapering off again in November. Manganese concentrations at SB @ Intake followed a similar pattern. However, an observed spike in autumn iron concentrations at SB @ Intake was offset from the peak in manganese, occurring approximately one month later from October through early December. Of the seven samples collected from the surface of FP @ DH in 2018, the manganese concentration was highest in September (0.14 mg/L). Elevated iron and manganese in the reservoir hypolimnions during the summer months may have led to the observed elevated surface concentrations at HB @ Intake and SB @ Intake in fall of 2018 after the autumn mixing event. That said, concentrations fluctuated throughout the year, so it was unclear the extent to which surface concentrations were impacted by the fall mixing. Despite elevated concentrations of manganese concentrations at FP @ DH (4 of 7 samples or 57 percent SMCL exceedance), manganese concentrations in treated drinking water met the SMCL standard in 2018 (CWD, 2019a).



(n, n%)= number of total samples, % of samples in excess of SMCL
Fe=Iron Samples, Mn=Manganese Samples

The following high Fe results are not displayed on the graph:
HB@Intake: 2.16 mg/L, 10.8 mg/L (5/31/2018 and 6/14/2018, respectively)
SB@Intake:11.4 mg/L, 11.1 mg/L (SB@Intake on 4/26/2018 and 6/7/2018, respectively)

However, the results are included in the statistics displayed on the graph and in this report.

Figure 18: Reservoir weekly intake and Fresh Pond deep hole iron and manganese surface results, 2018

8.4.2 2000 – 2018 Iron and Manganese Results

Stony Brook Reservoir consistently had the highest annual median surface concentrations of iron and manganese from 2000 – 2018 (Figure 19). Despite recharging with water from Stony Brook Reservoir, Fresh Pond had the lowest annual median iron concentrations of the three reservoirs, with median concentrations consistently below the 0.3 mg/L SMCL (Figure 19). Likewise, median annual manganese concentrations at FP @ DH were lower than SB @ Intake, although concentrations fluctuated between being above and below the 0.05 mg/L SMCL and were similar in magnitude to HB @ Intake.

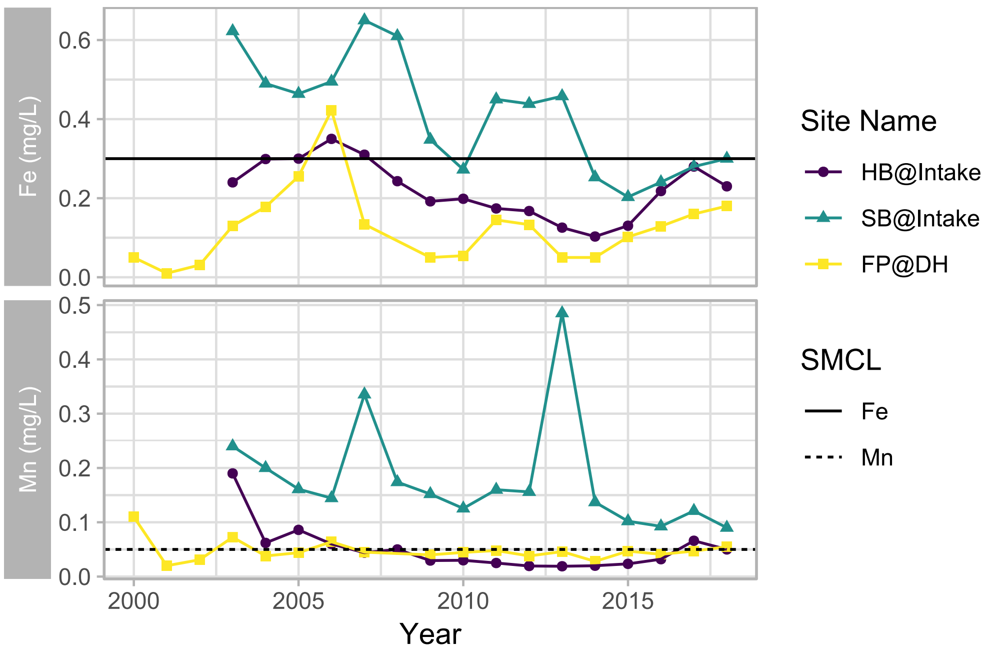


Figure 19: Median iron and manganese concentrations from HB @ Intake, SB@ Intake, and FP @ DH for all years with greater than 2 samples, 2000-2018

The relatively high iron and manganese concentrations at Stony Brook reservoir may have been due to differences in bed sediment compared to the other reservoirs. An analysis by the USGS in 1998 found that iron and manganese concentrations in Stony Brook Reservoir bed sediments were higher than sediments from Hobbs Brook Reservoir and higher than sediments analyzed from 135 sampling sites throughout the lower Charles River (Waldren and Bent, 2000). The median manganese bed sediment concentration of 1,100 mg/kg measured at SB @ DH was also higher than the 510 mg/kg measured during early 1990s in the eastern portion of Fresh Pond (Waldren and Bent, 2000). The relatively low annual median manganese surface concentrations at Fresh Pond are likely due to the less manganese-rich bed sediments combined with the aeration system. It is also possible that water is aerated as it travels through the conduit connecting the Stony Brook Reservoir and Fresh Pond, thereby reducing manganese concentrations prior to discharging into Fresh Pond.

Annual median iron and manganese concentrations at Stony Brook Reservoir appear to be trending downwards (Figure 19). There was no clear explanation for this possible trend. Statistical tests may be employed in the future to evaluate the statistical significance, if any, for this trend.

8.5 Bacteria

8.5.1 Bacteria Overview

Massachusetts regulations in 310 CMR 22.20B (6) implementing the Safe Drinking Water Act prohibit recreational activities in drinking water reservoirs. Nevertheless, CWD monitors *E. coli* bacteria results to assess whether the water in Cambridge reservoirs is safe for prolonged human contact with the water, as would be the case if swimming or wading were permitted. To protect human health, the Class A standard for primary contact recreation states that no single *E. coli* sample should exceed 235 colonies/100 ml and that the geomean for the most recent 6 months, based on at least 5 samples, should be at or below 126 colonies/100 ml. Following guidance outlined in the CALM 2016 guidance document, CWD analyzed geomeans for the April 1 – October 16 bathing season, rather than the most recent 6 months, and also analyzed sample results for the entire 2018 calendar year in relation to the 235 colonies/ml threshold.

8.5.2 Bacteria Results

Although not allowed, reservoir waters were generally safe for primary human contact in 2018. All reservoir geomean concentrations during the April 1 – October 15 bathing season were below 10 MPN/100 ml compared to the 126 colonies (or MPN)/ml Class A threshold, though HB @ Middle and HB @ Upper had less than the recommended 5 samples for performing the geomean analysis (Table 18). Only one sample from all reservoir sites, collected at SB @ Intake on August 2 (411 MPN/100 ml) was above the single sample threshold of 235 colonies/100 ml, equating to 2 percent of overall samples collected from the site (Table 18 and Figure 21). That reservoir waters were almost entirely free of *E. coli* single sample exceedances indicates excellent water quality unimpacted or minimally impacted by human fecal matter contamination (such as leaking septic system or illicit sewage discharges) and animal contributions. The *E. coli* exceedance at SB @ Intake on August 2nd may have been exacerbated by the 90 degree F air temperature since warm temperatures can stimulate bacterial growth (Figure 13 and Table 16). However, the exceedance could have been influenced by sampler contamination or temporary contributions from aquatic or avian animal inputs and it is not possible to draw a conclusion on the exceedance cause.

Reservoir waters in 2018 agreed with historic bacteria concentrations. Since CWD began sampling *E. coli* in 2006, annual median *E. coli* levels have remained below 235 MPN/100 ml and the exceedance rate at all three intake sites has never surpassed 6 percent (Figure 21 and Table 19). The maximum exceedance rates recorded at HB @ Upper and HB @ Middle were higher, at 25 percent. However, these higher exceedance rates may in part be due to the smaller sample size (4 samples, 1 exceedance).

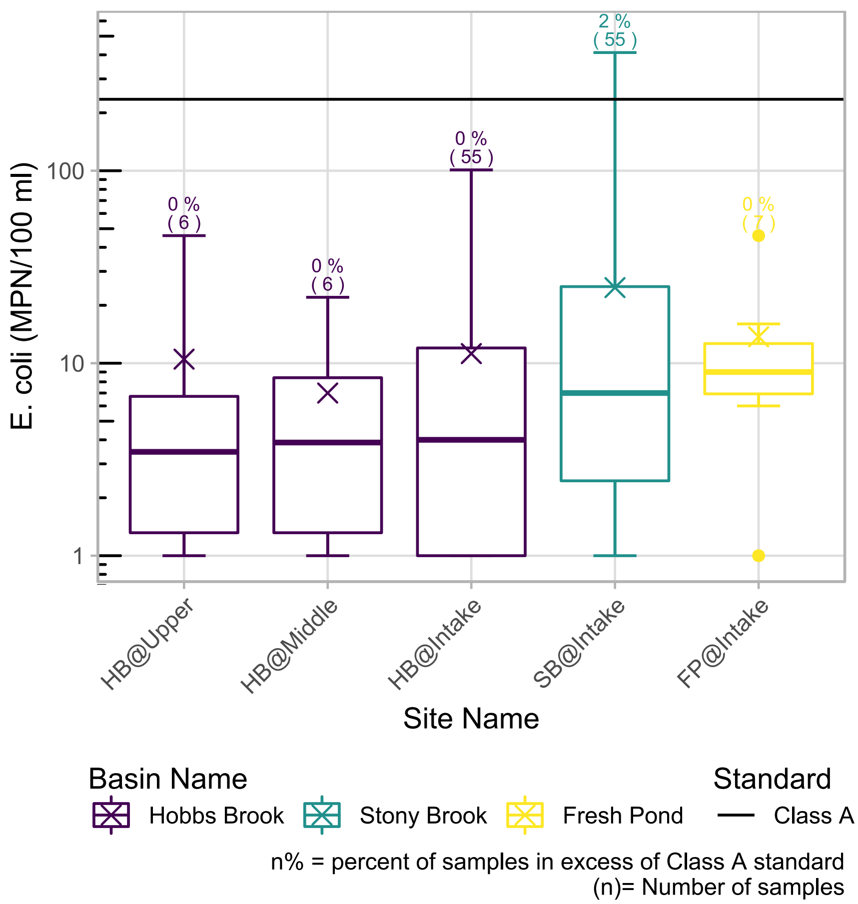


Figure 20: Reservoir E. coli surface sample results, 2018

Table 18: E. coli reservoir results, 2018

Site Name	Calendar Year 2018							April 1 – October 15	
	n>235	n	%	Min	Max	Median	Mean	n	Geomean
HB @ Upper	0	6	0	<1	46	4	11	3	5
HB @ Middle	0	6	0	<1	22	4	7	3	5
HB @ Intake	0	55	0	<1	101	4	11	32	6
SB @ Intake	1	55	2	<1	**411**	7	25	32	8
FP @ Intake	0	7	0	<1	46	9	14	5	6

n>235 = number of samples >235 MPN/100 ml, n=total number of sample, % = percent of samples >235 MPN/100 ml, Min=minimum, Max=maximum. Bolded statistics exceed the Class A criteria. Results less than the detection limit were set to the detection limit for the purposes of calculating statistics.

Table 19: Maximum reservoir E. coli exceedance rate years by site, 2006-2018

Site Name	Maximum Exceedance Rate Statistics			
	Year	n>235	n	%
HB @ Upper	2014	1	4	25
HB @ Middle	2014	1	4	25
HB @ Intake	2017	3	52	6
SB @ Intake	2011, 2012, 2014, 2017	2	52 (54 in 2012)	4
FP @ Intake	No exceedances	0	--	0

n>235 = number of samples >235 MPN/100 ml, n=total number of samples during exceedance year, % = percent of samples >235 MPN/100 ml

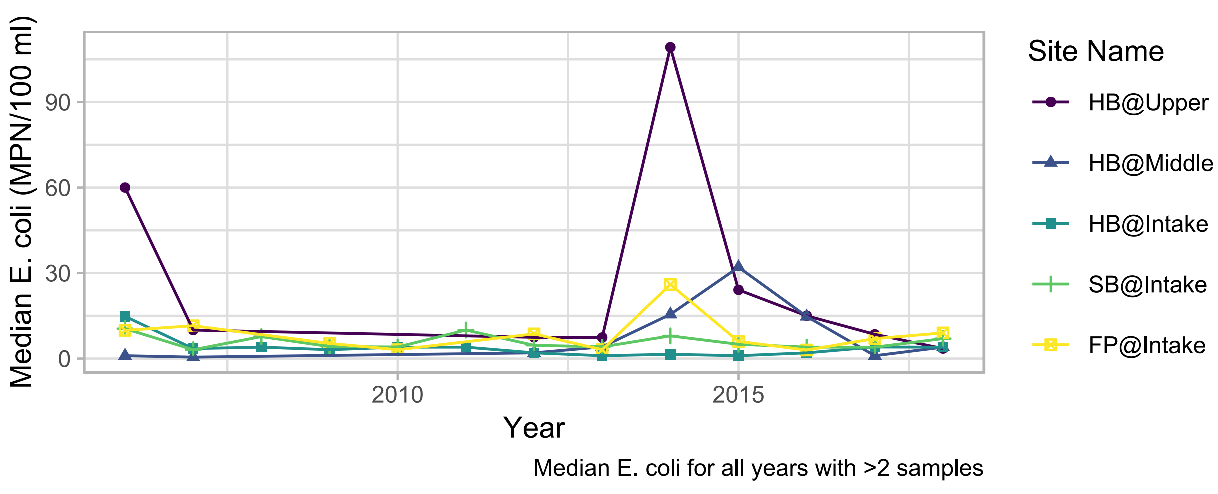


Figure 21: Median reservoir E. coli concentrations, 2006 – 2018

8.6 EUTROPHICATION

8.6.1 Eutrophication Overview

Excess nutrients encourage algae and plant growth which consume DO during respiration and decomposition and block light from penetrating through the water column (U.S Geological Survey, [n.d.]). Freshwater lakes are typically phosphorus limited, which means that a small input of phosphorous can result in a large increase in algae growth, whereas additional nitrogen inputs have minimal impact on algal growth (Waldren and Bent, 2000). One indicator of whether a lake is phosphorus limited, nitrogen limited, or neither is the molar ratio of nitrogen to phosphorous: ratios of greater than 20:1 suggest phosphorus limitation, less than 13:1 indicate nitrogen limitation, with 16:1 being the mean ratio in algal biomass and neither element considered limiting (Waldren and Bent, 2000).

EPA developed a set of nutrient criteria intended to represent reference conditions for nutrient levels in lakes, reservoirs, and tributaries which have not experienced accelerated eutrophication due to anthropogenic inputs (U.S. Environmental Protection Agency 2000, 2001). MA DEP has not adopted these nutrient-specific criteria and instead evaluates whether waters meet the Aquatic Life, Aesthetic, and Primary Contact Recreation uses for nutrients based on an assortment of different primary producer biological and physico-chemical screening guidelines (Massachusetts Division of Watershed Management Watershed Planning Program, 2016). If a water body is impaired aesthetically for nutrients, MA DEP also considers it impaired for the Primary Contact Recreational use (Massachusetts Division of Watershed Management Watershed Planning Program, 2016).

Another way to assess the state of eutrophication in a water body is Carlson's trophic state index (TSI), a dimensionless numerical index ranging from 0 – 100 which is used to categorize water bodies based on their productivity state (North American Lake Management Society Secchi Dip-In Program, [n.d]). TSI can be calculated using chl-*a*, TP, or SD; in this report, all TSI values were calculated using chl-*a*.

8.6.2 Eutrophication Results Surface Samples 2018

Surface water quality as evaluated by eutrophication status in 2018 improved between the upper basins (HB @ Upper and HB @ Middle) and lower basin (HB @ DH) of Hobbs Brook Reservoir, Stony Brook Reservoir (SB @ DH), and Fresh Pond (FP @ DH) (Table 20 and Figure 22). Median TSI was in the mesotrophic zone at all reservoir sites except Fresh Pond, which was oligotrophic (TSI = 37).[6] Because TSI was calculated using chl-*a*, the chl-*a* concentrations also dropped between Hobbs Brook, Stony Brook, and Fresh Pond reservoirs (Table 20 and Figure 22).

Likewise, median TP and turbidity levels decreased between the three Hobbs Brook Reservoir basins and Fresh Pond, with median TP (0.032 mg/L) and turbidity (6.9 NTU) at HB @ Upper falling to <0.011 mg/L (TP) and 0.61 NTU (turbidity) at FP @ DH (Figure 22 and Figure 23; Table 20). SD transparency followed a similar pattern, increasing in transparency between the HB @ DH and FP @ DH, confirming the trend in improved water quality (Table 20 and Figure 22). Although median TP and turbidity concentrations at SB

[6] The detection limit for chl-*a* was 2 mg/m^3 which is equivalent to a TSI of 37. HB @ Upper, SB @ DH, and FP @ DH each had at least one chl-*a* sample below 2 mg/m^3 in 2018. Therefore, TSI statistics at these sites may be artificially high.

@ DH were slightly elevated and median SD transparency slightly reduced compared to HB @ DH, the increase in productivity at SB @ DH indicated by these metrics was not apparent in Fresh Pond. TOC median concentrations also steadily declined between HB @ Upper (6.8 mg/L), HB @ Middle (6.0 mg/L), and HB @ DH (3.1 mg/L), before increasing at SB @ DH (4.3 mg/L) and decreasing again to mirror the HB @ DH concentration at FP @ DH (3.5 mg/L) (Figure 23).

Of the DEP Primary Producer Biological and Physico-chemical screening guidelines evaluated by CWD in 2018, no reservoir sites showed signs of nutrient impairment for the Aquatic Life, Primary Contact Recreation, or Aesthetics uses. Surface chl-*a* concentrations at all sites remained below 16 mg/m^3 with transparency as measured by SD greater than 1.2 meters (Table 20 and Figure 22). For the sites with more than two samples during the summer season, the summer mean TP concentration was below 0.025 mg/L (Figure 22). As previously discussed, SB @ DH did have elevated pH in in the first 2 to 3 meters of the water column during the August profile, but the elevated pH was not accompanied by other indicators of serious nutrient impairment (Figure 10 and Figure 22; Table 20).

CWD did not formally monitor for other indicators of nutrient enrichment used by MA DEP to make impairment decisions, such as the percent macrophyte coverage and qualitative aesthetic observations such as odors, scums, and algae bloom presence and extent. No informal observations, except for the brief bloom discussed previously in Hobbs Brook Reservoir (Figure 14), uncovered aesthetically objectionable algae blooms. Non-rooted macrophyte coverage was estimated to be less than a quarter of the reservoir surface area based on visual observations during sampling visits to the reservoirs. However, rooted or subsurface macrophyte growth was present at Hobbs Brook and Stony Brook and may have been more extensive, although the scope and type of subsurface macrophyte vegetation growth was not analyzed.

It should be noted that, when compared against the EPA nutrient criteria for SD and TP, the reservoirs do show signs of eutrophication compared to the reference conditions identified by EPA. SD readings at all reservoirs, except for two readings at FP @ DH, were less transparent than the 4.9 meter EPA criterion (Figure 22 and Table 20). All six TP samples from HB @ Upper and HB @ Middle exceeded the 0.008 mg/L criterion as did 2 of 6 samples at HB @ DH and 5 of 6 samples at SB @ DH (Figure 22 and Table 20). One of seven surface samples at FP @ DH may have exceeded the criterion, as one sample was below the 0.0160 mg/L detection limit and the duplicate sample was above the detection limit, which averaged to <0.0112 mg/L (Table 20). However, the TP exceedance rate at FP @ DH was less than at SB @ DH even though Stony Brook supplied water to Fresh Pond.

The improvement in water quality and clarity observed in 2018 between the upper, middle, and lower basin of Hobbs Brook Reservoir was likely due the settling of larger particles and organic matter as the water slowly moved through the reservoir basins. The slight increase in TP, TOC, and turbidity and decrease in SD transparency at SB @ DH compared to HB @ DH may have been due to differences in bed sediment composition between the reservoirs and differences in external loads of phosphorus from the watershed catchments. For example, Waldren and Bent (2001) found that bed sediments at Stony Brook Reservoir had three times more phosphorus than sediments in Hobbs Brook and Fresh Pond reservoirs. The Stony Brook Reservoir drainage area was also more forested than that of the Hobbs Brook Reservoir ’s. As such, the higher TP and TOC concentrations at Stony Brook Reservoir may partially reflect natural organic matter inputs from the landscape rather than algal growth in the reservoir, especially since the median chl-*a* concentration at SB @ DH (2.9 mg/m^3) was similar to HB @ DH (3.6 mg/m^3) (Table 20). The

Stony Brook Reservoir retention time was also the shortest of the three reservoirs at only two weeks (see Section 11). This may have prevented sediments from the Stony Brook subcatchment inflow from settling out of the water column. By contrast, the retention time in Hobbs Brook Reservoir was 15 months in 2018, which allowed for turbidity and TP to fall out of the water column.

Finally, the superior water quality at Fresh Pond compared to Hobbs Brook Reservoir and Stony Brook Reservoir with respect to eutrophication was likely aided by the aeration system. The aeration system was designed to minimize algae growth by encouraging mixing and aerobic conditions in the water body. By maintaining aerobic conditions, the system aimed to prevent internal phosphorus loading from sediment releases and avoid a build-up of undecomposed organic matter.

Table 20: Reservoir surface eutrophication and nutrient impairment indicators, 2018

Site Name	Indicator	n outside bounds	n	%	Min	Max	Median	Mean
HB @ Upper	TSI	--	6	--	37	54	45	45
	Chl-*a*	0	6	0	2.0	10.8	4.7	5.5
	TP	6	6	100	**0.014**	**0.045**	**0.032**	**0.031**
HB @ Middle	TSI	--	6	--	40	49	45	45
	Chl-*a*	0	6	0	2.6	6.3	4.6	4.5
	TP	6	6	100	**0.015**	**0.035**	**0.026**	**0.025**
HB @ DH	TSI	--	6	--	39	51	43	44
	Chl-*a*	0	6	0	2.3	8.4	3.6	4.2
	TP	2	6	33	<0.011	**0.027**	<0.011	**0.014**
	SD	6	6	100	**1.5**	**4.5**	**3.8**	**3.5**
SB @ DH	TSI	--	6	--	37	48	41	42
	Chl-*a*	0	6	0	2.0	5.9	2.9	3.3
	TP	5	6	83	<0.011	**0.020**	**0.013**	**0.015**
	SD	6	6	100	**2.5**	**4.0**	**3.0**	**3.2**
FP @ DH	TSI	--	7	--	37	45	37	39
	Chl-*a*	0	7	0	2.0	4.2	2.0	2.4
	TP	1	7	14	<0.011	**<0.011***	<0.011	<0.011
	SD	7	9	78	**3.5**	5.5	**4.0**	**4.3**

n outside bounds = number of samples outside the EPA nutrient criteria levels (TP, SD) or DEP Primary Producer Biological screening guideline (chl-*a*). n= number of samples, %= percent of samples above/below criteria, min= minimum, max=maximum. -- = no standards or criteria apply. Samples below the detection level were set to the detection level for the purposes of calculating means.

Bolded results exceed the EPA nutrient criteria. The detection limit for TP was 0.0106 mg/L in 2018. Therefore, any sample <0.0106 mg/L was not considered an exceedance of the EPA Nutrient Criterion. No results were outside the Producer Biological or Physico-chemical screening guideline minimum/maximums for chl-*a*, summer mean TP, or SD.

The detection limit for chl-*a* was 2 mg/m^3 which is equivalent to a TSI of 37. Therefore, TSI statistics at HB @ Upper, SB @ DH, and FP @ DH, all of which had at least one chl-*a* sample below 2 mg/m^3, may be artificially high.

*Result of the average of a sample and FDUP where one sample was above and the other below the detection limit. Considered an exceedance of the 0.008 mg/L EPA nutrient criteria.

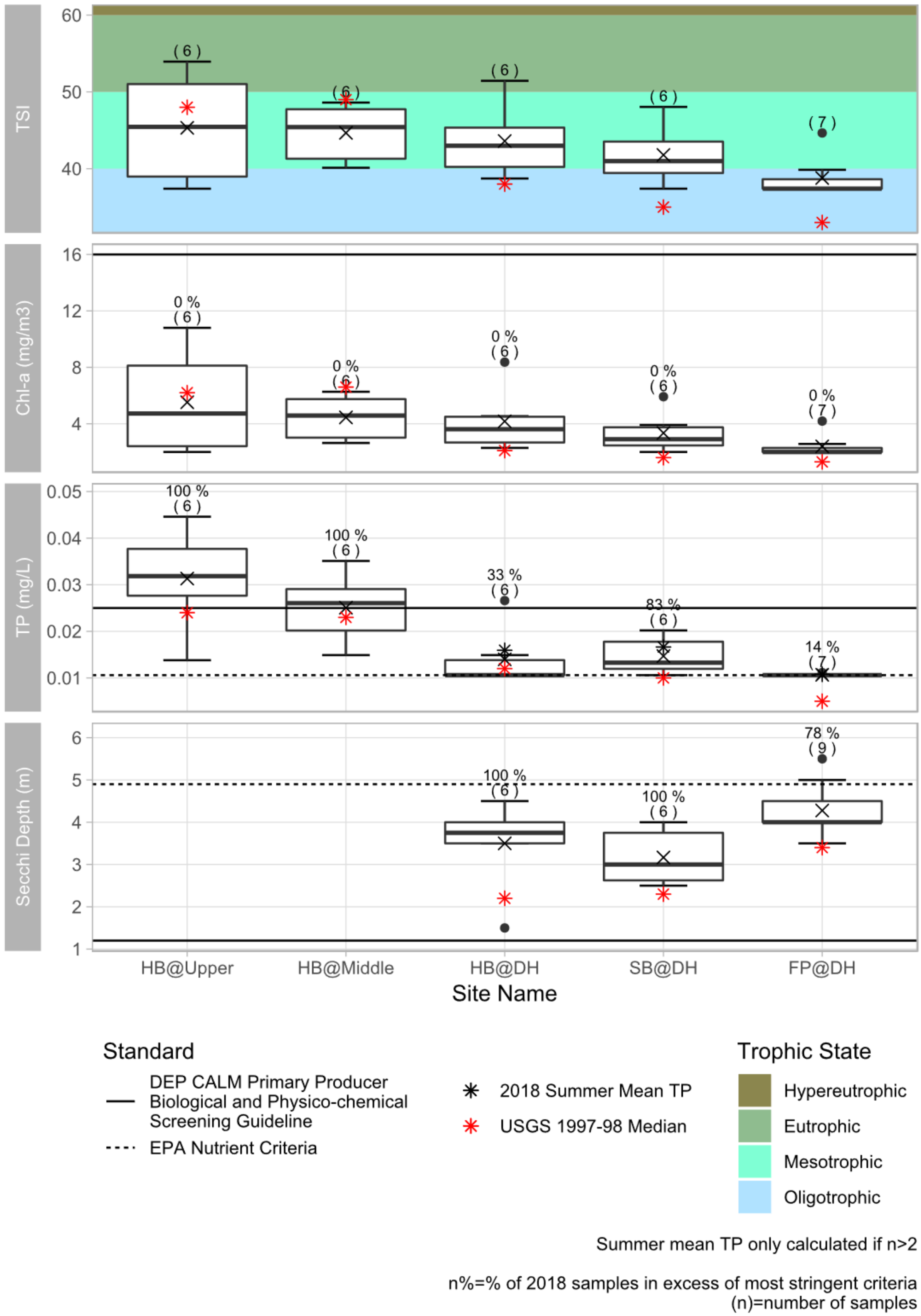


Figure 22: Reservoir eutrophication indicators, 2018 and 1997 - 1998 USGS baseline study

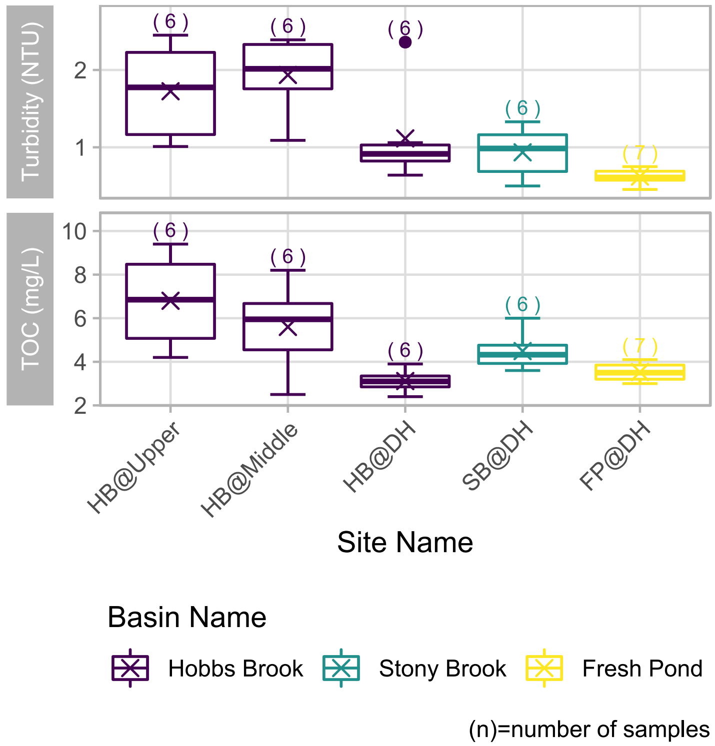


Figure 23: Reservoir turbidity and total organic carbon (TOC), 2018

8.6.3 Eutrophication Surface Sample Comparison to USGS 1997-1998 Baseline Study

The reduction in median TSI between the upper basins of Hobbs Brook Reservoir and Fresh Pond in 2018 followed a similar cascading pattern to the 1997 – 1998 USGS baseline study (Figure 22).[7] One difference between 2018 and the baseline study was that the 2018 median TP concentration increased, and median SD transparency decreased, between HB @ DH and SB @ DH before improving again at FP @ DH (Figure 22). In the baseline study, there appeared to be a more consistent trend in water quality with median TP concentrations decreasing between HB @ DH, SB @ DH, and FP @ DH and median SD transparency increasing (Figure 22). While it is possible that SB @ DH has experienced slight eutrophication since the 1997 – 1998 baseline study, it is also possible that this change in pattern was due to improved water quality in Hobbs Brook Reservoir. Over the past 20 years, redevelopment projects in the watershed improved stormwater treatment practices with the goal of preventing sediment and phosphorus from entering the reservoir. Another possible explanation is that CWD operated an aeration system in Stony Brook Reservoir that ceased operations in 2014, which may have led to a subsequent increase in internal cycling of TP and nutrient growth.

For example, the 1997-1998 surface median TP concentration at SB @ DH was 0.010 mg/L compared to the slightly higher 0.013 mg/L median in 2018 (Figure 22). At HB @ DH, the median TP concentration was 0.012 mg/L during the baseline study and <0.011 in 2018, which may indicate a small or large change depending on how far below the detection limit the true TP value had dropped. The larger difference

[7] Median TSI at Fresh Pond during the USGS baseline study (33) was lower than in 2018 (37). However, the median TSI levels in 2018 may be artificially high due to the 2 mg/m³ detection limit of the chl-*a* test, which equates to a TSI of 37. In the baseline study, the detection limit of chl-*a* was lower which permitted TSI levels of 33 (FP @ DH) and 35 (SB @ DH).

occurred with SD transparency, with all three reservoirs becoming more transparent since 1997-1998. HB @ DH gained the most clarity since the baseline study, increasing from a median SD transparency of 2.2 meters in 1997-1998 to 3.8 meters in 2018 (Figure 22).

8.6.4 Comparison of 2018 Reservoir Surface and Bottom Eutrophication Results

Water quality samples collected from the hypolimnion at the deep hole sites at Hobbs Brook and Stony Brook Reservoirs during thermal stratification were more eutrophic than surface samples (Figure 24). For surface samples, median TSI categorized HB @ DH and SB @ DH as mesotrophic and FP @ DH as oligotrophic. While FP @ DH remained oligotrophic in the hypolimnion (median TSI = 37), the HB @ DH and SB @ DH hypolimnion median TSIs were eutrophic with individual samples in the hypereutrophic range (Figure 24). Chl-*a,* which was used to calculate TSI; TP; and turbidity were also higher in the hypolimnion than in the epilimnion at HB @ DH and SB @ DH (Figure 24). The elevated chl-*a* in the hypolimnion at HB @ DH and SB @ DH indicated that subsurface algal growth occurred during summer stratification. The elevated TP may also have been from algae and other organic detritus settling near the bottom of the reservoirs. The low TP in the FP @ DH hypolimnion was likely attributable to the aeration system preventing internal phosphorus loading.

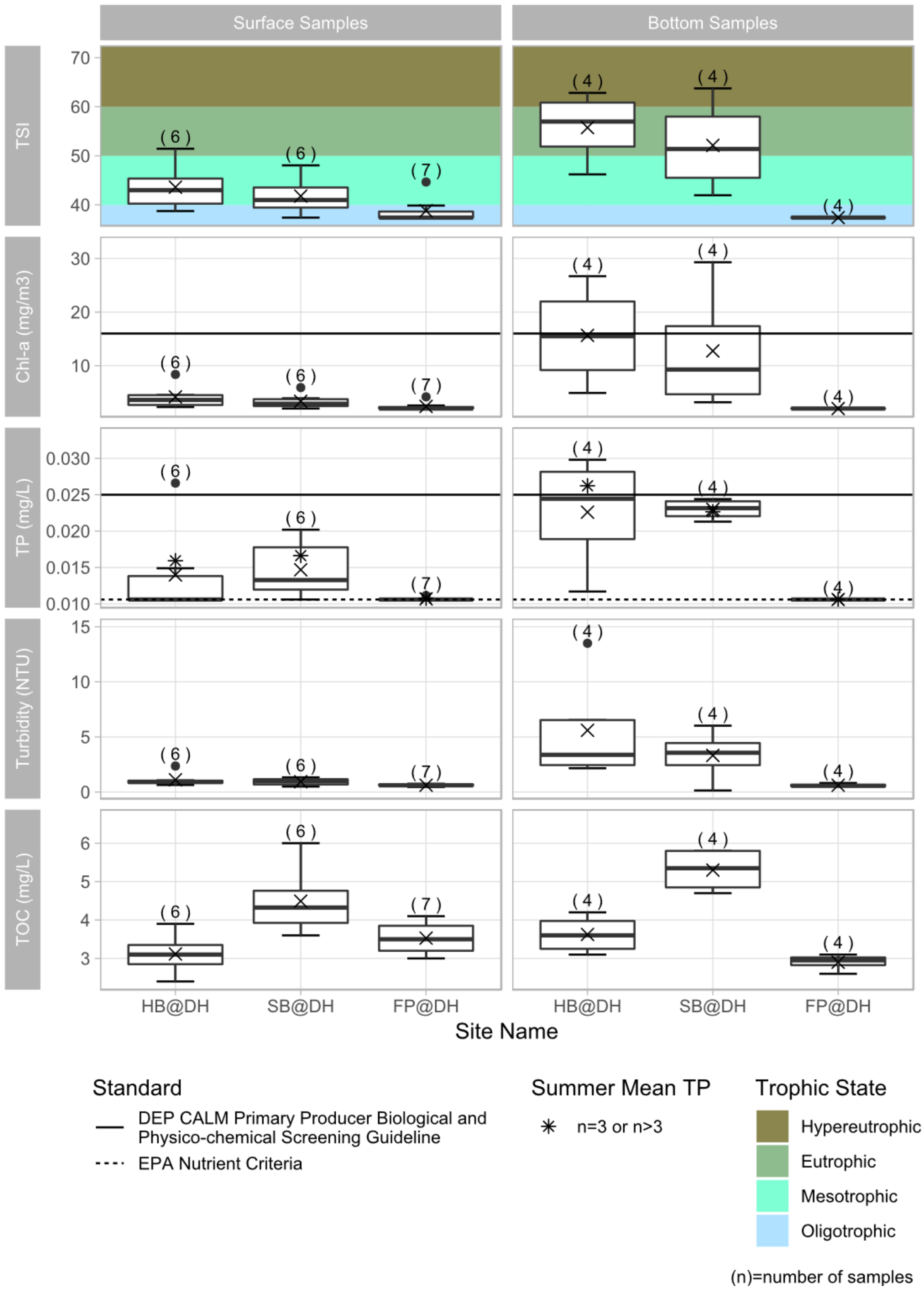


Figure 24: Reservoir surface and bottom comparison of eutrophication indicators, turbidity, and TOC, 2018

8.6.5 Reservoir Phosphorus Limitation and Nitrogen, 2018

The mean molar ratio of TN to TP was greater than 20:1 at all reservoir sites, ranging from 64 to 176. This indicates that all reservoirs were prone towards phosphorus limitation and that increased inputs of nitrogen would be unlikely to result in increased productivity (Table 21). However, all reservoir sites in 2018 were compared against reference conditions for nitrogen defined by the EPA nutrient criteria (Table 22 and Figure 25).

Table 21: Mean molar ratio of Total Nitrogen (TN) to Total Phosphorus (TP), 2018

Site Name	Mean TN:TP
HB @ Upper	64
HB @ Middle	64
HB @ DH	85
SB @ DH	130
FP @ DH	176

One or more samples at all sites exceeded the EPA nutrient criteria for TKN (0.43 mg/L), nitrate and nitrite nitrogen (0.05 mg/L), and TN (0.48 mg/L) in 2018 (Table 22 and Figure 25). However, the concentrations were not a water quality concern due to the apparent phosphorus limitation of the reservoirs. Further, all reservoir sites were well below the 10 mg/L nitrate MCL, the level at which nitrate concentrations become a public health concern in drinking water.

HB @ DH generally had the lowest overall concentrations of all nitrogen species except ammonia, for which the median concentration was lowest at FP @ DH (Table 22 and Figure 25). Nitrate and nitrite nitrogen and TN were highest at Fresh Pond (medians of 0.462 mg/L and 0.957 mg/L, respectively) followed by SB @ DH (0.246 mg/L and 0.746 mg/L, respectively). The aeration system likely helped maintain the nitrate concentrations at Fresh Pond and depress ammonia concentrations. Nitrate is most prevalent in aerobic environments because nitrate becomes reduced to elemental nitrogen and ammonia under anaerobic conditions. Median TKN (the sum of organic nitrogen and ammonia nitrogen) was highest in the upper basins of Hobbs Brook Reservoir and likely attributable to organic nitrogen due to the higher productivity in the upper basins (Figure 22). Septic system leachate and fertilizer use, which were likely more common in the less developed Stony Brook watershed, may have contributed to the higher nitrate and nitrite nitrogen reservoir concentrations compared to the sewered and more developed Hobbs Brook Reservoir watershed.

Table 22: Reservoir nitrogen surface concentrations, 2018

Site Name	Parameter	n outside bounds	n	%	Min	Max	Median	Mean
HB @ Upper	TKN	5	6	83	0.402	**0.710**	**0.551**	**0.564**
	Ammonia N	NA	6	NA	0.099	0.138	0.116	0.117
	Nitrate and nitrite N	3	5	60	<0.060	**0.319**	**0.060**	**0.156**
	TN	5	5	100	**0.646**	**0.798**	**0.721**	**0.730**
HB @ Middle	TKN	5	6	83	0.309	**0.617**	**0.467**	**0.467**
	Ammonia N	NA	6	NA	0.069	0.155	0.125	0.121
	Nitrate and nitrite N	3	5	60	<0.060	**0.365**	**0.100**	**0.182**
	TN	5	5	100	**0.525**	**0.828**	**0.717**	**0.681**
HB @ DH	TKN	2	6	33	0.304	**0.487**	0.349	0.375
	Ammonia N	NA	6	NA	0.060	0.147	0.108	0.103
	Nitrate and nitrite N	3	6	50	0.019	**0.222**	**0.076**	**0.105**
	TN	4	6	67	0.358	**0.581**	**0.486**	0.480
SB @ DH	TKN	4	6	67	0.345	**0.669**	**0.447**	**0.484**
	Ammonia N	NA	6	NA	0.080	0.139	0.112	0.112
	Nitrate and nitrite N	5	6	83	0.048	**0.805**	**0.246**	**0.333**
	TN	6	6	100	**0.542**	**1.25**	**0.746**	**0.817**
FP @ DH	TKN	3	7	43	0.100	**0.658**	0.403	0.393
	Ammonia N	NA	7	NA	0.058	0.148	0.085	0.088
	Nitrate and nitrite N	7	7	100	**0.138**	**0.664**	**0.462**	**0.456**
	TN	7	7	100	**0.562**	**1.07**	**0.957**	**0.848**

NA = Not applicable

Bolded values exceed the EPA nutrient criteria

Detection limit values were 0.01 and 0.05 mg/L for nitrate nitrogen, depending on whether the sample was analyzed by the CWD lab or the contract lab. The detection limit for nitrite nitrogen was 0.005 mg/L or 0.01 mg/L. For the purposes of calculating statistics, the sample results were set to the detection limit. However, if the sum of the nitrate and nitrite nitrogen was above the 0.05 mg/L EPA nutrient criteria but both sample results were below the detection limit, then the sample was not considered an exceedance.

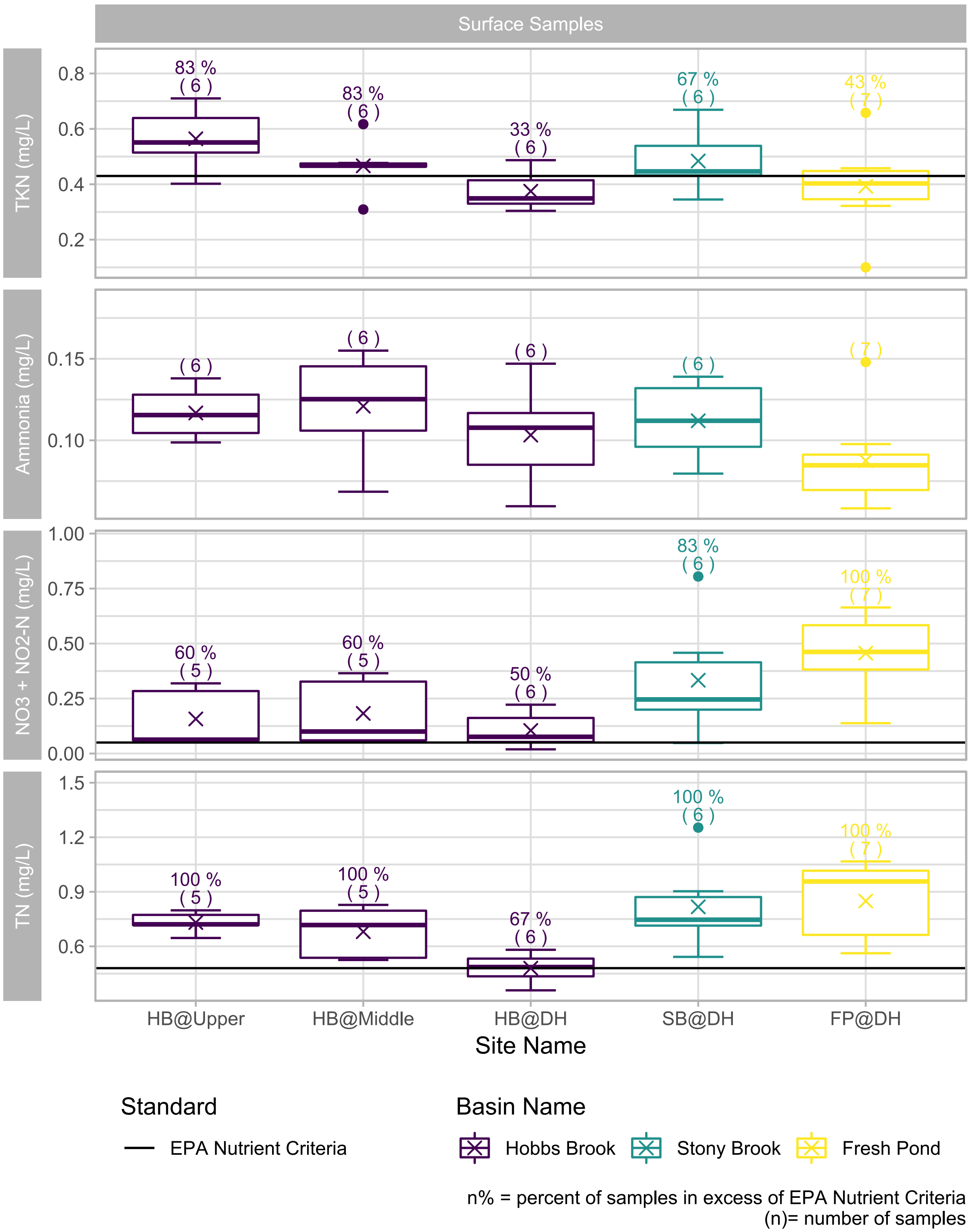


Figure 25: Reservoir nitrogen, 2018

8.7 RESERVOIR SODIUM AND CHLORIDE

8.7.1 Sodium and Chloride Overview

Hobbs Brook Reservoir is vulnerable to sodium and chloride pollution from deicing salts used on state and federal highways, parking lots, local roadways, and other salt-treated impervious surfaces. Hobbs Brook Reservoir is also subject to groundwater salt loads from an historic groundwater salt plume created by a previously unprotected MassDOT salt storage facility (Geotechnical Engineers Inc., 1985). Bordered by I-95, Stony Brook Reservoir is also affected by sodium and chloride pollution from deicing. However, drainage from less developed catchment areas in the Stony Brook watershed, such as the SB @ Viles and Summer St catchments, help to dilute higher-salt inflows. Because the reservoirs are located in succession, releases of water from Hobbs Brook Reservoir during the drier summer and fall months can affect the sodium and chloride concentrations downstream at Stony Brook Reservoir and Fresh Pond Reservoir. Elevated chloride concentrations can impact aquatic life and result in salty tasting drinking water. MA DEP uses the EPA chronic and acute toxicity standards (230 mg/L four-day average and 860 mg/L, respectively) to determine whether waters meet the Aquatic Life use for chloride. The SMCL is slightly higher, at 250 mg/L. Sodium levels in drinking water are compared against the 20 mg/L ORS Guideline to inform consumers who must manage their sodium intake for health purposes.

8.7.2 2018 Sodium and Chloride Results

Elevated chloride concentrations in the Hobbs Brook Reservoir lower basin in 2018 suggested that the water body was chloride impaired and potentially did not meet the Aquatic Life use for this metric. All weekly grab samples (51 of 51) collected from HB @ Intake and HB @ DH (6 of 6) exceeded the 230 mg/L EPA chronic toxicity criterion (Figure 26 and Table 23). USGS provisional continuous chloride data from the outlet of Hobbs Brook Reservoir (station 01104430) were consistently above 230 mg/L in 2018 and supported the hypothesis that the 230 mg/L four-day average concentration criterion was exceeded in 2018 (Figure 27).[8] Weekly water quality samples from HB @ Intake also exceeded the 250 mg/L SMCL in 86 percent of samples (Figure 26 and Table 23). However, the SMCL applies to treated drinking water and no grab samples from Fresh Pond, the terminal reservoir in the water supply system, exceeded the SMCL in 2018 (0 of 7 samples).

Despite the proximity of the Hobbs Brook Reservoir upper and middle basins to Route 2 and I-95, and despite the historic groundwater salt plume in the Salt Depot subcatchment feeding the upper basin, median chloride concentrations at HB @ Middle (225 mg/L) and HB @ Upper (169 mg/L) were less than 230 mg/L (Figure 26 and Table 23). This is likely due to dilution from HB @ Mill St and ungagged areas of surface and groundwater flow in the upper and middle basin relative to the ungagged areas with higher impervious cover and roadway miles in the lower basin (Figure 3 and Table 2).

Similarly, even though I-95 borders Stony Brook Reservoir, 2018 median chloride concentrations at SB @ DH (211 mg/L) and SB @ Intake (188 mg/L) were lower than 230 mg/L. Only one sample from SB @ DH (1 of 6) exceeded 230 mg/L, while just 14 percent of samples from SB @ Intake (7 of 51) exceeded the EPA chronic toxicity criterion, two of which were also above the 250 mg/L SMCL (Figure 26 and Table 23). Excluding the Hobbs Brook Reservoir watershed (HB Below Dam drainage area), the Stony Brook Reservoir

[8] Chloride concentrations were estimated by the USGS using continuous specific conductance measurements and a regression equation developed by Smith (2013).

drainage area is 13.6 percent impervious and has 8.0 miles of roads per square mile, less than that of the Hobbs Brook Reservoir at 17 percent impervious and 11.1 miles of roads per square mile (Table 3).

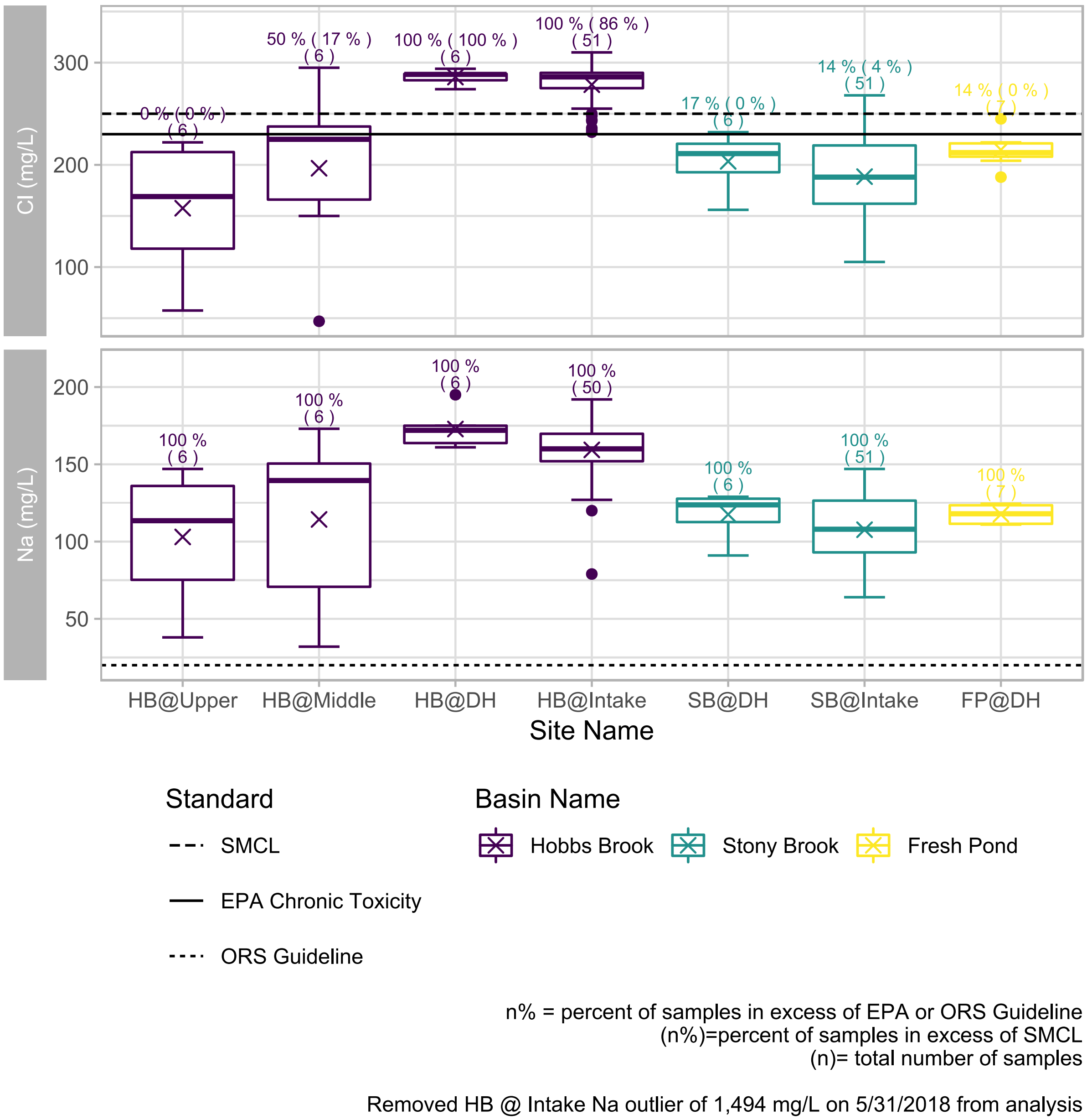


Figure 26: Reservoir sodium and chloride concentrations, 2018

Table 23: Reservoir chloride statistics, 2018

Site Name	n > 230 mg/L	n > 250 mg/L	n	% > 230 mg/L	% > 250 mg/L	Min	Max	Median	Mean
HB @ Upper	0	0	6	0	0	58	222	169	158
HB @ Middle	3	1	6	50	17	47	**295**	225	197
HB @ DH	6	6	6	100	100	**274**	**294**	**289**	**286**
HB @ Intake	51	44	51	100	86	**232**	**310**	**286**	**278**
SB @ DH	1	0	6	17	0	156	**232**	211	203
SB @ Intake	7	2	51	14	4	105	**268**	188	188
FP @ DH	1	0	7	14	0	188	**245**	212	215

n > 230 mg/L, n > 250 mg/L = number of samples above the EPA chronic toxicity criterion and the SMCL, respectively
n = number of total samples
% > 230 mg/L, % > 250 mg/L = % of samples above the EPA chronic criterion and the SMCL, respectively.
Min = minimum, Max=maximum

Bolded values exceed 230 mg/L EPA chronic toxicity criterion, underlined values exceed the 250 mg/L SMCL

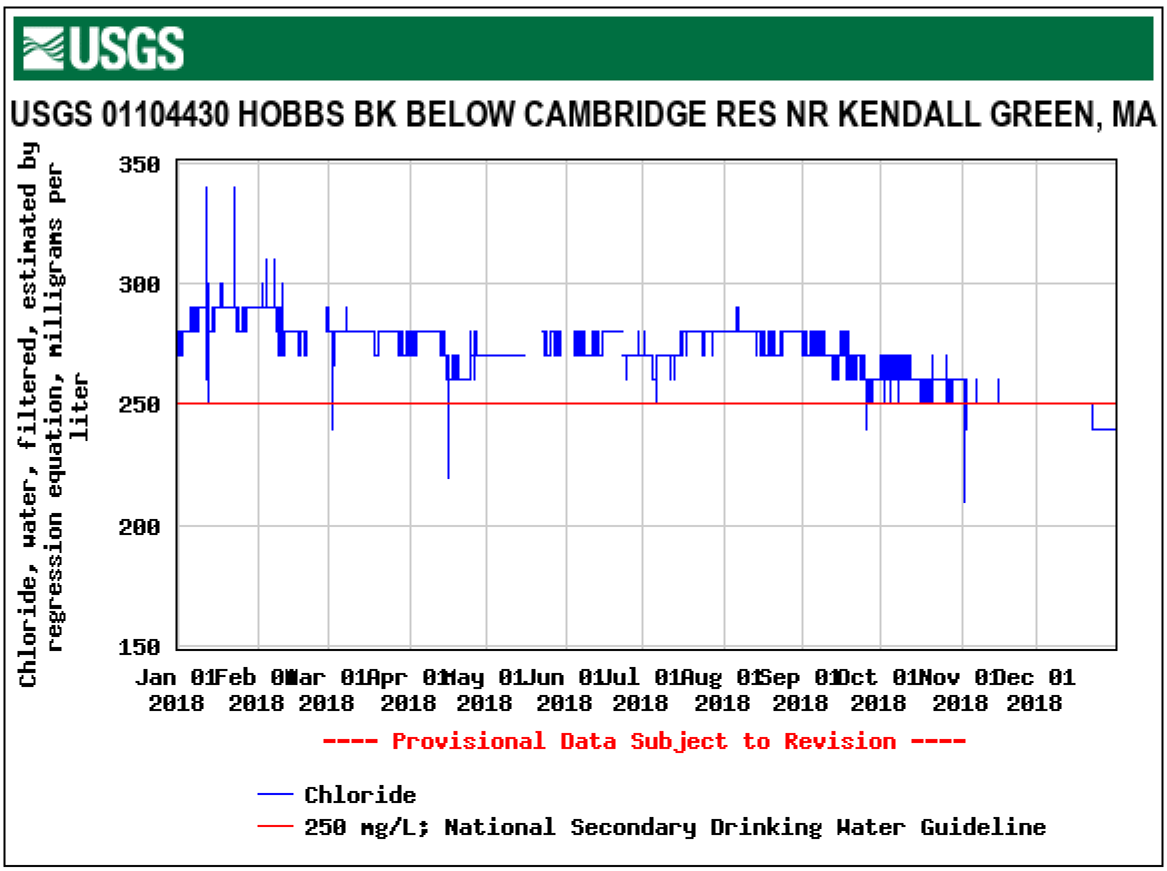


Figure 27: Provisional USGS continuous chloride concentrations at HB Below Dam, 2018

All chloride exceedances at SB @ Intake occurred towards the end of the Hobbs Brook Reservoir summer water release period (Figure 28). With only a two-week retention time (see Section 12), Stony Brook Reservoir water chemistry is easily influenced by sustained water releases from Hobbs Brook Reservoir. Fresh Pond has a larger storage volume than Stony Brook Reservoir (1.5 billion gallons compared to 418 million gallons) and a 10-year average retention time of 4.1 months. Therefore, changes in water chemistry in Fresh Pond due to summer water releases from Hobbs Brook Reservoir are not as great in magnitude as at Stony Brook Reservoir. Concentrations of chloride at Fresh Pond Reservoir were relatively consistent in 2018, although one sample did exceed 230 mg/L on November 8th (Figure 28). However, HB @ Intake and SB @ Intake samples collected on the same date were also anomalously high compared to other samples collected during the fall time period (Figure 28). As such, the exceedance may have been the result of a laboratory or sampling error rather than a true exceedance.

Sodium concentrations mirrored chloride concentration patterns in 2018, with median and maximum concentrations highest in the Hobbs Brook Reservoir lower basin (Figure 26 and Table 24). All samples from all sites exceeded the 20 mg/L ORS Guideline (Figure 26 and Table 24). As with chloride, Stony Brook Reservoir sodium concentrations were highest during the Hobbs Brook Reservoir summer water release period (Figure 28). Unlike chloride, sodium concentrations did not spike on November 8th at FP @ DH, further suggesting that the chloride EPA chronic toxicity standard was a false result.

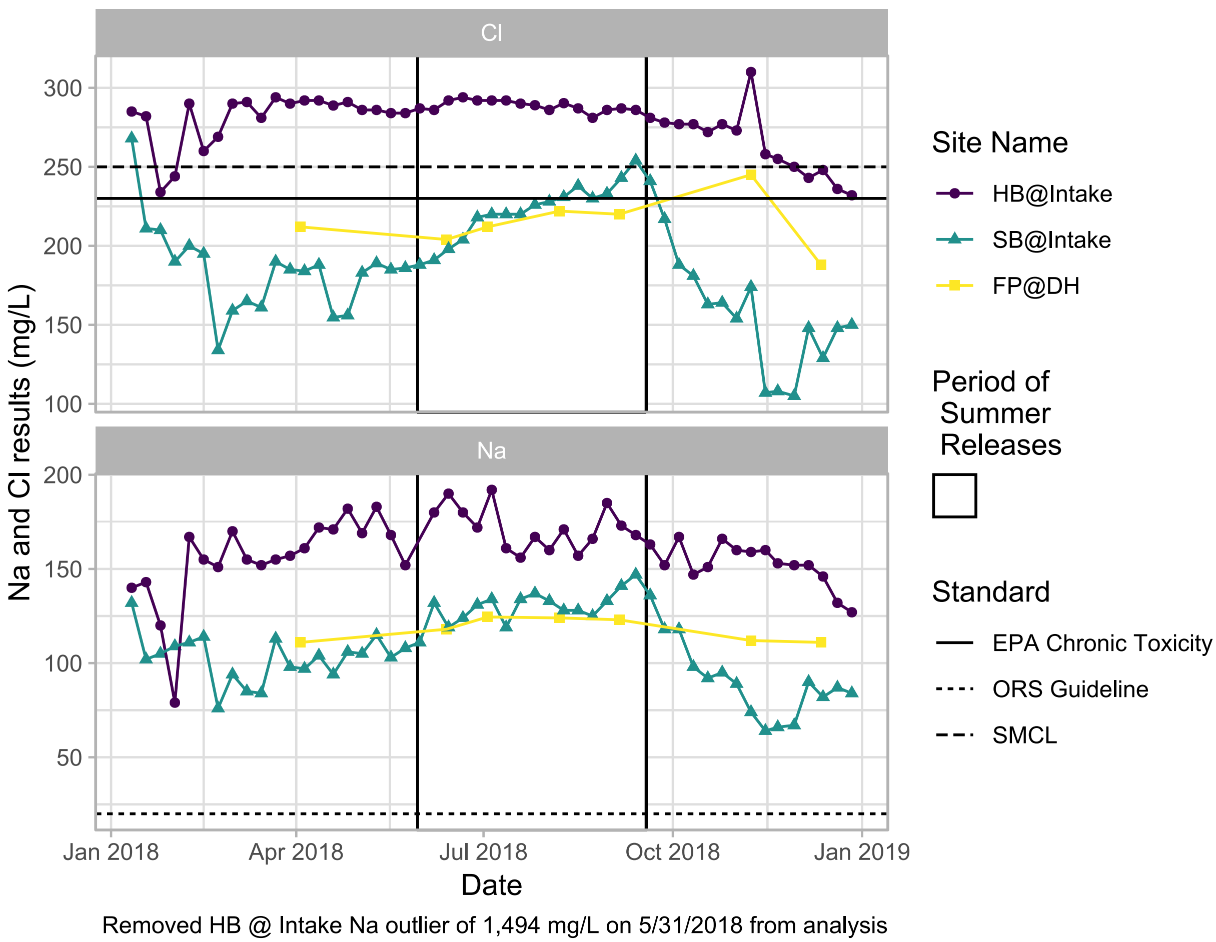


Figure 28: HB @ Intake, SB @ Intake, and FP @ DH sodium and chloride results, 2018

Table 24: Reservoir sodium statistics, 2018

Site Name	n > 20 mg/L	n	%	Min	Max	Median	Mean
HB @ Upper	6	6	100	38	147	114	103
HB @ Middle	6	6	100	32	173	140	114
HB @ DH	6	6	100	161	195	172	173
HB @ Intake	50	50	100	79	192	160	159
SB @ DH	6	6	100	91	129	124	118
SB @ Intake	51	51	100	64	147	108	108
FP @ DH	7	7	100	111	125	118	118

n > 20 mg/L = number of samples above ORS Guideline
n = number of total samples
% > 20 mg/L = % of samples above the ORS Guideline
Min = minimum, Max=maximum
HB @ Intake outlier of 1,494 mg/L from 5/31/2018 excluded from analysis

8.7.3 Sodium and Chloride Trends

Median sodium and chloride concentrations in Hobbs Brook Reservoir were relatively stable from 2003 until 2012. After 2012, median concentrations trended upward through 2017 (Figure 29 and Figure 30). A similar upward pattern was observed at Fresh Pond and, to a certain extent, at Stony Brook Reservoir, where median concentrations at SB @ Intake peaked in 2015 before leveling off. Median sodium and chloride concentrations stabilized or decreased in 2018 at all three reservoirs, signaling a potential reversal of the increasing trends.

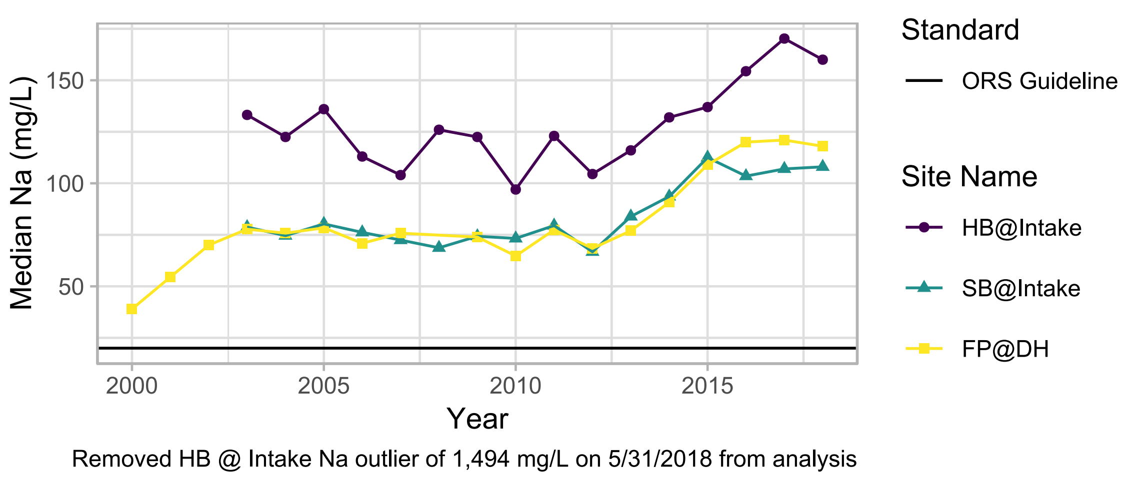


Figure 29: Median reservoir sodium concentrations for all years with greater than two samples, 2000 - 2018

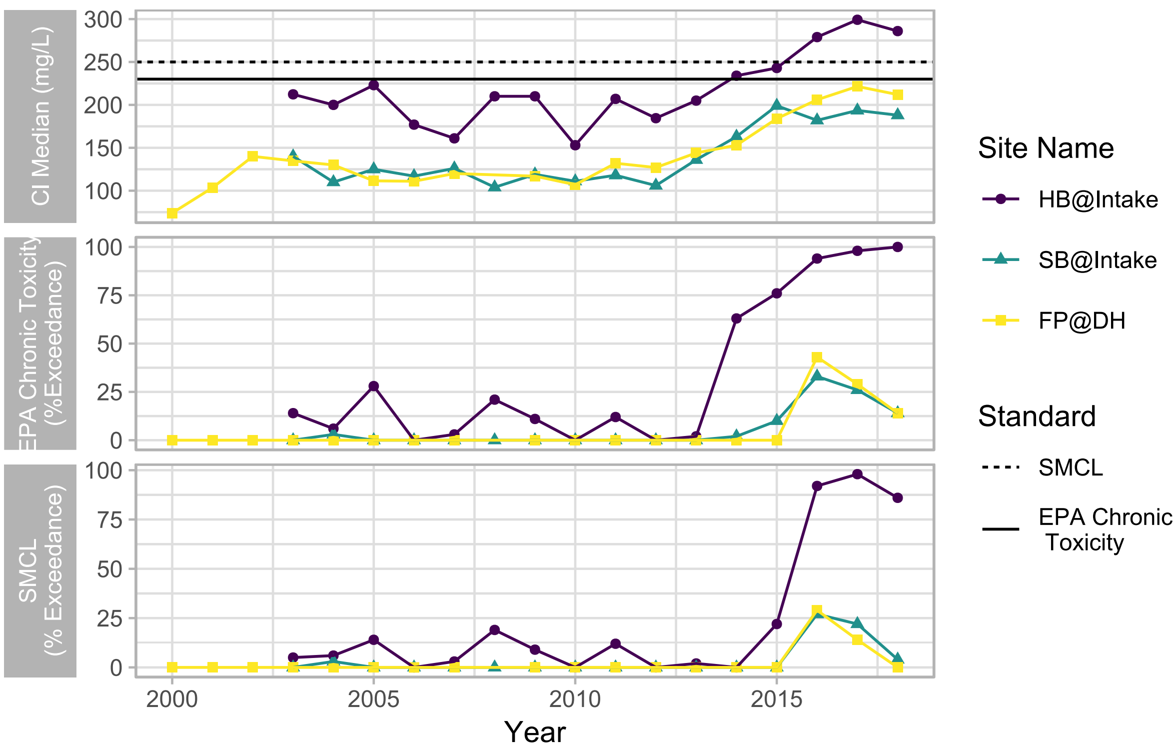


Figure 30: Median reservoir chloride concentrations and exceedances for all years with greater than two samples, 2000 - 2018

The rise in sodium and chloride concentrations between 2012 and 2017 was likely the result of dry weather and drought conditions. Less precipitation translates into less runoff, which means less dilution of salt-impacted base-flow. According the NOAA Bedford Hanscom Field monitoring station, precipitation between 2012 and 2017 was below the 45.71 inch 1981-2010 normal (Figure 31). In addition, the Massachusetts Drought Management Taskforce declared a drought on July 1, 2016 that lasted until April 30, 2017 (Massachusetts Executive Office of Energy and Environmental Affairs, 2017).

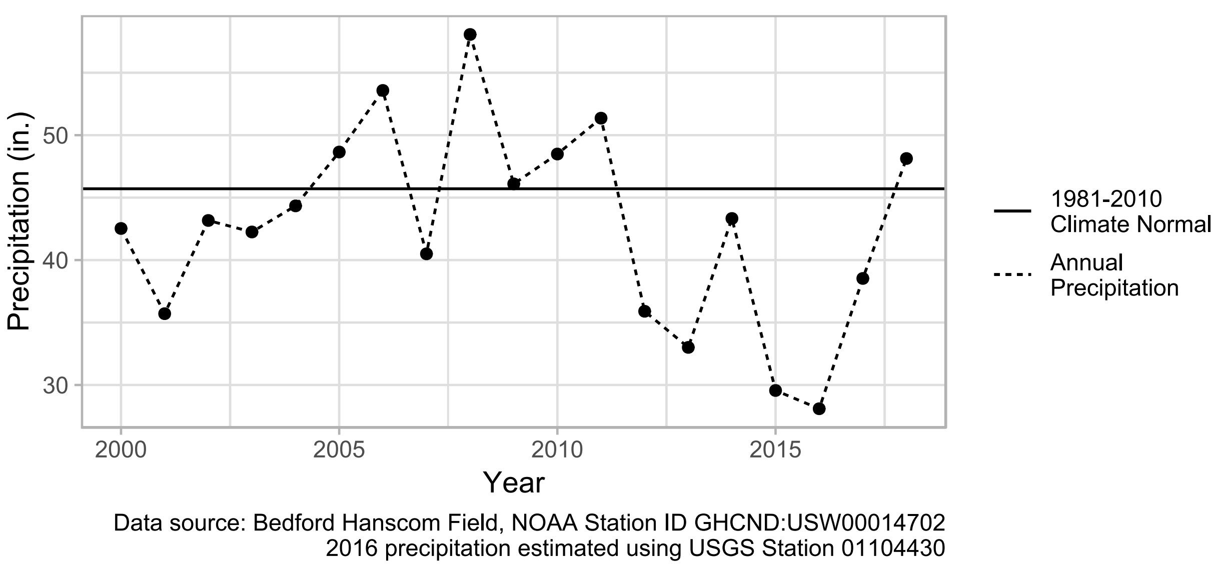


Figure 31: Annual precipitation at Bedford Hanscom Field, 2000 - 2018

Although median chloride values at all three reservoirs began their upward trend in 2012, coinciding with the start of below normal precipitation, median concentrations at Hobbs Brook Reservoir did not exceed the 230 mg/L EPA chronic toxicity standard until 2014 (Figure 30 and Figure 31). By 2015, median concentrations were above 250 mg/L SMCL and remained elevated through 2018. Median chloride levels at Stony Brook and Fresh Pond reservoirs remained below 230 mg/L despite the drought. However, chloride exceedance rates at all three reservoirs increased dramatically during the 2016-2017 drought.

For example, the HB @ Intake 230 mg/L EPA chronic toxicity exceedance rate jumped from 2 percent in 2013, to 63 percent in 2014, and peaked at 100 percent of samples in 2018 (Figure 30). At Stony Brook Reservoir, weekly intake samples rarely exceeded either chloride criterion before the drought. However, starting in 2015, 10 percent of weekly intake samples exceeded the EPA chronic toxicity standard rising to 33 percent in 2016. Chloride concentrations at SB @ Intake were high enough to also exceed the 250 mg/L SMCL in 27 percent of samples in 2016. Exceedance rates of both chloride criteria dropped in 2017 (26 percent and 22 percent) and 2018 (12 percent and 4 percent) as the drought conditions lessened, allowing the reservoir to recharge with less-salt impacted water from the Stony Brook subwatershed.

The impact of the drought on chloride exceedances extended to Fresh Pond. Prior to 2016, all samples collected by CWD at FP @ DH were less than both the 230 mg/L EPA chronic toxicity standard and the 250 mg/L SMCL. During the drought, chloride concentrations were high enough that 2 of 7 samples (29 percent) in 2016 and 1 of 7 samples (14 percent) in 2017 exceeded the 250 mg/L SMCL. Because Fresh Pond is the terminal reservoir in the drinking water supply, these exceedances had the potential to impact the taste of finished water produced at the treatment plant.

Fortunately, precipitation was above normal in 2018, and 2018 sodium and chloride data suggest that the reservoir water quality started to recover from the drought. Weekly sodium and chloride concentrations in Hobbs Brook Reservoir steadily declined from October 2018 through December 2018 (Figure 27 and Figure 28). Exceedance rates dropped at all reservoir sites dropped in 2018 except for the 230 mg/L EPA toxicity standard at Hobbs Brook Reservoir, where 100 percent of samples exceeded the criterion despite the decrease in the median concentration compared to 2017 (Figure 30).

It is important to note that, from a volume perspective, the Hobbs Brook Reservoir had recovered completely by the end of 2018. Figure 32 shows the development of drought conditions beginning in 2015, before the official start of the drought in 2016, when the minimum annual volume in Hobbs Brook Reservoir was near the 10-year low observed in 2008. The reservoir volume then reached a historic low in October of 2016, the height of the drought. This minimum node would have been even lower had CWD not purchased supplemental water from MWRA from October through December 2016. The start of volumetric drought recovery became evident in 2017, with an annual minimum storage volume in Hobbs Brook Reservoir of approximately 1,500 million gallons, three times higher than in 2016. After a year of above normal precipitation in 2018, the Hobbs Brook Reservoir had fully recovered with a minimum annual storage volume of just under 2,000 million gallons. By contrast, the *maximum* storage volume in 2016 during the drought was just over 2,000 million gallons.

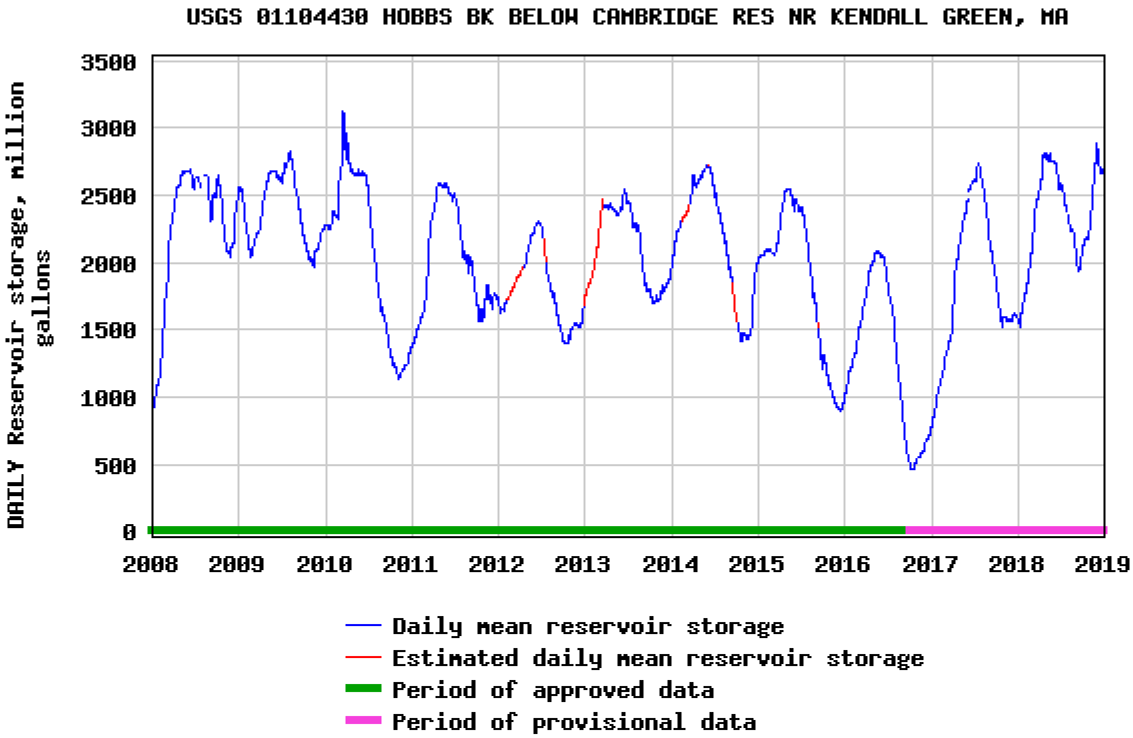


Figure 32: Hobbs Brook Reservoir storage volume from USGS station 01104430, 2008-2018

As the water quality data show, despite the volumetric recovery, Hobbs Brook Reservoir had yet to recover chemically from the drought in 2018 since sodium and chloride concentrations were still elevated. Continued above normal precipitation in 2019 and in future years will be needed to maintain the decreasing sodium and chloride trends observed in 2018. It remains to be seen when, if ever, sodium and chloride concentrations return to pre-drought levels. Given that the post-drought recovery time for water quality exceeds the volumetric recovery time, CWD may need to consider future drought management strategies to preserve water quality in addition to water quantity. CWD will continue to work with municipalities, private land owners, and MassDOT to reduce salt loads in the watershed where possible. With climate change, CWD may experience more frequent droughts and will need to manage the reservoirs accordingly.

8.7.4 1997-1998 USGS Baseline and 2018 Specific Conductance

Specific conductance measures the ability of water to conduct electrical current. It is often closely related to the concentration of salts, such as sodium and chloride ions, in the water. In fact, the USGS uses specific conductance to estimate the real-time sodium and chloride concentrations at various sites throughout the Cambridge watershed, including Hobbs Brook Reservoir. A comparison of specific conductance profiles collected by the USGS during the 1997 – 1998 baseline study and by CWD in 2018 shows that specific conductance profile values in 2018 had roughly doubled since the baseline study (Figure 33).

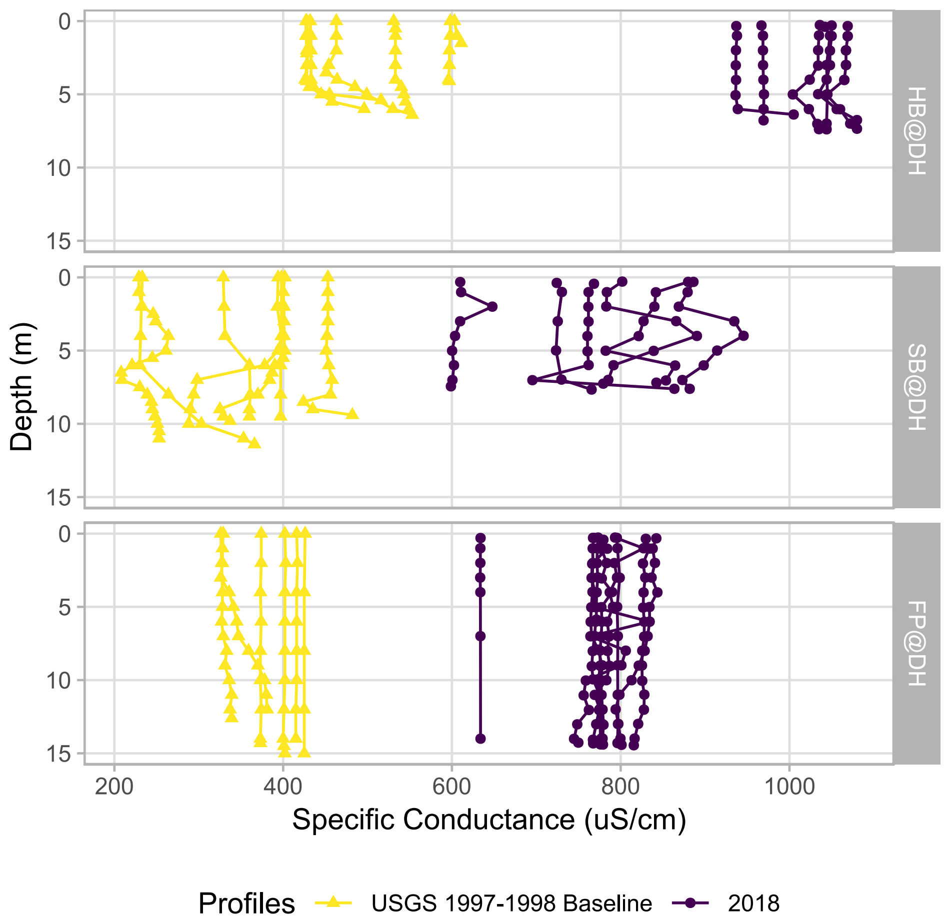


Figure 33: Reservoir specific conductance profiles, USGS 1997 - 1998 baseline study and 2018

In both time periods, specific conductance profiles were highest in the Hobbs Brook Reservoir (Figure 33). Profiles at Stony Brook Reservoir were the most variable, a response to changes in water chemistry throughout the year due to releases of relatively high-salt water from Hobbs Brook Reservoir in the fall and summer months. Even though Fresh Pond is downstream of Hobbs Brook and Stony Brook reservoirs, specific conductance profiles at FP @ DH were less variable than at SB @ DH. This was presumably due to the longer retention time at Fresh Pond, which means that greater inputs of high-salt water from Hobbs Brook Reservoir via Stony Brook Reservoir would be required to flush the reservoir and achieve a similar change in water chemistry. Not surprisingly, because the Stony Brook Reservoir feeds Fresh Pond Reservoir, water chemistry at Fresh Pond in both time periods was more similar to Stony Brook Reservoir than to Hobbs Brook Reservoir.

9 TRIBUTARY BASE-FLOW WATER QUALITY

As a surface water supply, tributaries in the Cambridge watershed feed the Stony Brook and Hobbs Brook reservoirs. Therefore, analyzing tributary water quality and catchment area land use can help inform management decisions and explain reservoir water quality conditions. In 2018, water quality data were analyzed to answer the following questions:

- How did tributary water quality explain reservoir water quality?
- Were tributary waters of high enough quality to support aquatic life?
- Were tributary waters safe for primary contact recreation and allow for pleasing aesthetics?
- How did water quality in 2018 compare against historic data?
- Were tributary waters salt impaired?
- How did water quality patterns correspond with land use in tributary catchment areas?

Similar to the reservoirs, tributary water quality results were compared against the Class A water quality standards, MCL and SMCLs, ORS Guidelines, and EPA nutrient criteria. Tributary water quality results in 2018 were compared against data collected by CWD since 2000. The USGS baseline study reported tributary water quality statistics for stormflow and base-flow combined (Waldron and Bent, 2001). As such, comparisons of 2018 tributary water quality to the baseline study are discussed in Section 10.

9.1 PH

To meet the Aquatic Life use, Class A tributaries must remain within a pH range of 6.5-8.3 unless naturally occurring. This is the same range required for reservoirs. In 2018, HB @ Mill St, Tracer Ln, and MBS were the only tributary sites with pH measurements outside the pH Class A range (Figure 34 and Figure 35; Table 25). All excursions from the required pH range were below the 6.5 lower bound. At MBS, a single low excursion occurred on August 29th as indicated by both the *in situ* (6.35) and lab (6.48) pH measurements. Three of six samples analyzed in the CWD lab from HB @ Mill St were outside the Class A bounds on June 12th (6.41), August 29th (6.37), and October 18th (6.49) (Figure 34 and Figure 35; Table 25). A single water quality sample collected at Tracer Ln on December 13th and analyzed by the CWD lab was also just below 6.5 at 6.48. However, none of the *in situ* measurements at HB @ Mill St or Tracer Ln were outside the acceptable bounds in 2018.

All three sites were downstream of wetlands and mud, silt, and organic matter were often visible in the channels. The low pH readings at HB @ Mill St, Tracer Ln, and MBS could have been the result of active decomposition, resulting in the release of CO_2 via microbial respiration which can mix with water to reduce pH (increase H^+ ion concentrations). At HB @ Mill St, a beaver dam was observed immediately upstream of the sampling site during the June 12th site visit. Observation of the dam coincided with the first excursion from the pH standard in 2018. The dam appeared to slow the flow and increase organic debris in the downstream channel. Continued monitoring at HB @ Mill St will be needed to observe whether pH excursions become more frequent with the upstream beaver dam.

Overall, *in situ* pH was higher than the pH recorded in the CWD lab (Figure 34 and Table 25). This discrepancy was partially the result of samples collected from under ice cover. Carbon dioxide mixing with previously ice-covered water during the collection and transport of samples can result in lower pH.

However, the tendency for the *in situ* readings to exceed the laboratory readings extended to site visits without ice cover and may represent a real difference between the two measurements. The CWD *in situ* water quality probe underwent a series of repairs in 2019, so this discrepancy may also have been a warning signal of equipment decline. Regardless, the excursions below the acceptable pH range were slight (less than 0.5 SU), historically rare (Figure 35), and may have been a function of highly organic environments rather than a sign of serious water quality impairment. Further, the slightly acidic excursions observed in the tributaries did not appear to impact the reservoirs, where the few observed excursions were the result of elevated pH. However, if future excursion rates at HB @ Mill St, Tracer Ln, and MBS develop into an increasing trend, CWD may need to evaluate whether a management intervention is warranted.

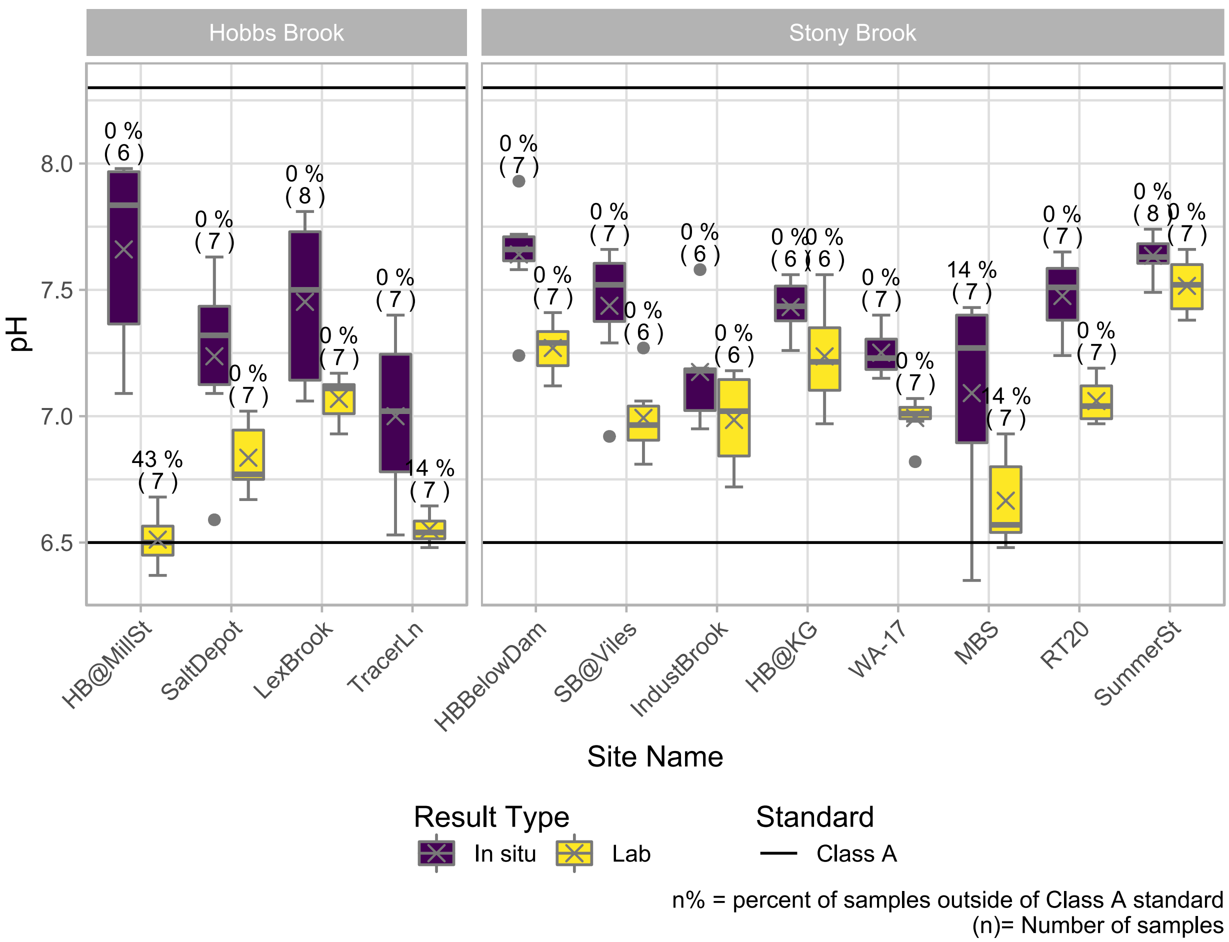


Figure 34: Tributary base-flow pH water quality probe results measured in situ and in the CWD laboratory by reservoir basin, 2018

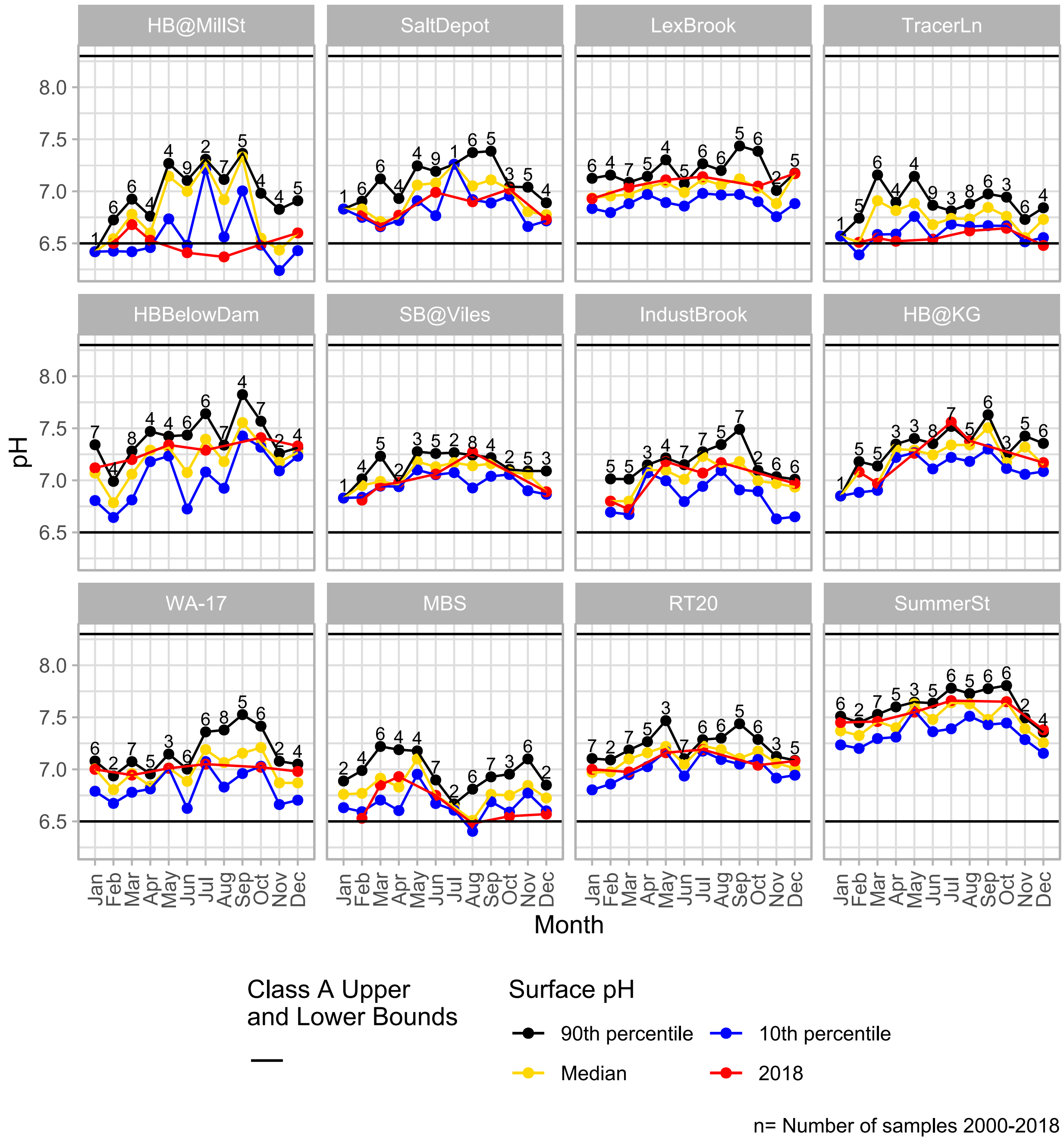


Figure 35: Tributary monthly pH statistics from water quality samples measured in the CWD laboratory, 2000 – 2018

Table 25: Tributary in situ and laboratory pH statistics, 2018

Basin Name	Site Name	pH Type	n <6.5 or >8.3	n	%	Min	Max	Median	Mean
Hobbs Brook	HB @ Mill St	lab	3	7	43	**6.37**	6.68	6.50	6.51
		in situ	0	6	0	7.09	7.98	7.84	7.66
	Salt Depot	lab	0	7	0	6.67	7.02	6.77	6.84
		in situ	0	7	0	6.59	7.63	7.32	7.24
	Lex Brook	lab	0	7	0	6.93	7.17	7.11	7.07
		in situ	0	8	0	7.06	7.81	7.50	7.45
	Tracer Ln	lab	1	7	14	**6.48**	6.65	6.54	6.55
		in situ	0	7	0	6.53	7.40	7.02	7.00
Stony Brook	HB Below Dam	lab	0	7	0	7.12	7.41	7.29	7.27
		in situ	0	7	0	7.24	7.93	7.66	7.64
	SB @ Viles	lab	0	6	0	6.81	7.27	6.97	6.99
		in situ	0	7	0	6.92	7.66	7.52	7.44
	Indust Brook	lab	0	6	0	6.72	7.18	7.02	6.99
		in situ	0	6	0	6.95	7.58	7.18	7.18
	HB @ KG	lab	0	6	0	6.97	7.56	7.22	7.24
		in situ	0	6	0	7.26	7.56	7.44	7.43
	WA-17	lab	0	7	0	6.82	7.07	7.01	6.99
		in situ	0	7	0	7.15	7.4	7.23	7.25
	MBS	lab	1	7	14	**6.48**	6.93	6.57	6.67
		in situ	1	7	14	**6.35**	7.43	7.27	7.09
	RT 20	lab	0	7	0	6.97	7.19	7.04	7.06
		in situ	0	7	0	7.24	7.65	7.51	7.48
	Summer St	lab	0	7	0	7.38	7.66	7.52	7.52
		in situ	0	8	0	7.49	7.74	7.63	7.64

n = number of samples, n <6.5 or >8.3 = number of samples outside Class A pH bounds, % = percent of samples outside the Class A pH bounds, min = minimum pH, max = maximum pH, bolded pH statistics are outside the Class A pH bounds

9.2 Temperature

Similar to the reservoirs, tributary water temperatures in 2018 were compared against the Class A warm water fishery and CFR standards to evaluate whether the streams thermally supported the Aquatic Life use. Discrete temperature measurements at all warm water fishery sites sampled by CWD in 2018 were cooler than the 28.3 degree C Class A temperature standard (Figure 36). USGS collected continuous temperature data at the following warm water fishery sites in 2018: HB @ Mill St, Salt Depot, Lex Brook, Tracer Ln, HB Below Dam, WA-17, and Summer St. These data largely confirmed CWD findings, with maximum temperatures in 2018 under 28.3 degrees C at all sites except for Lex Brook, Tracer Ln, and WA-17 (Table 26).[9] Lex Brook and WA-17 both exceeded 28.3 degrees C during a storm event on August 3, 2018, one day after the maximum daily air temperature exceeded 90 degrees F (Figure 13 and Figure 37). Both the Lex Brook and WA-17 catchments have high percentages of impervious surfaces (33.0 percent and 37.1 percent, respectively) which likely generated warm runoff from pavement heated during the hot weather (Table 3). Storm runoff upstream of WA-17 displaces standing open water in the rotary basin which is subject to thermal heating.

[9] Temperature data for 2018 included provisional data points subject to change by USGS.

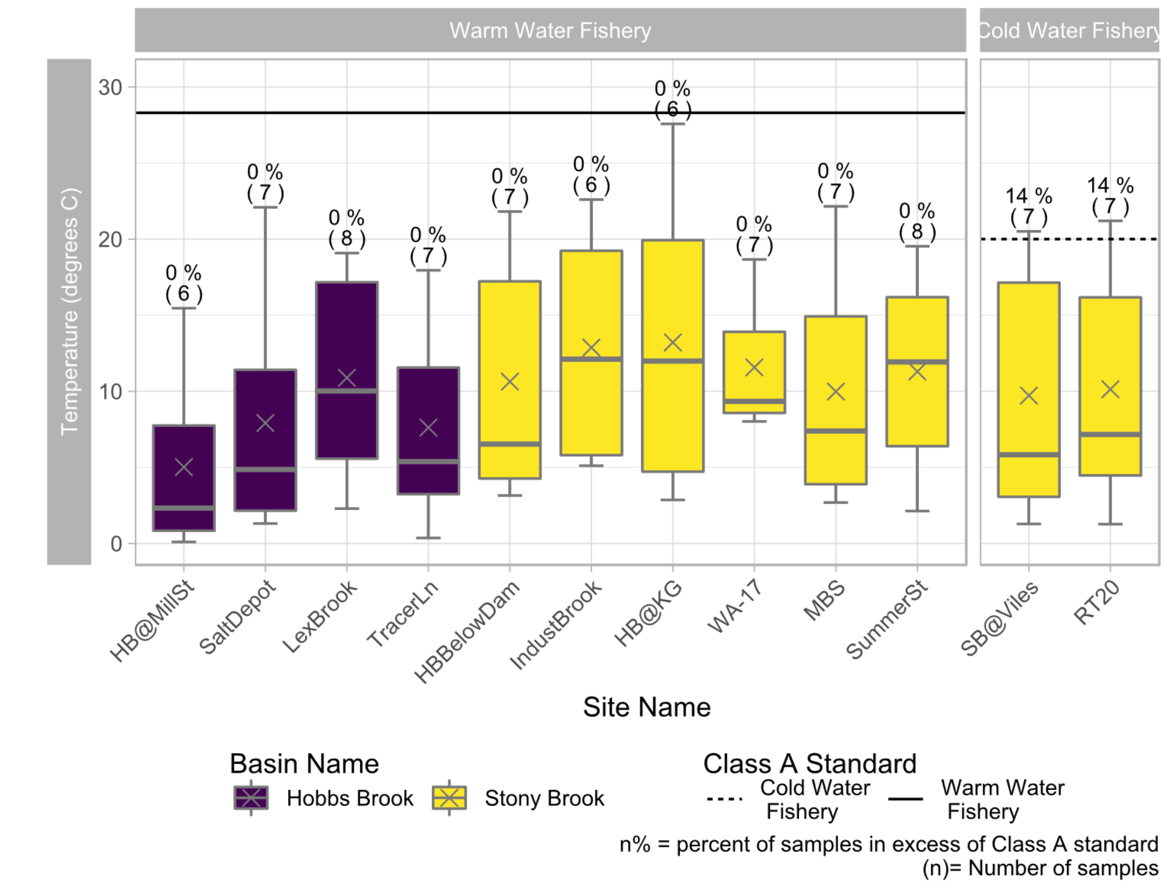


Figure 36: CWD Tributary Base-flow Temperature Results, 2018

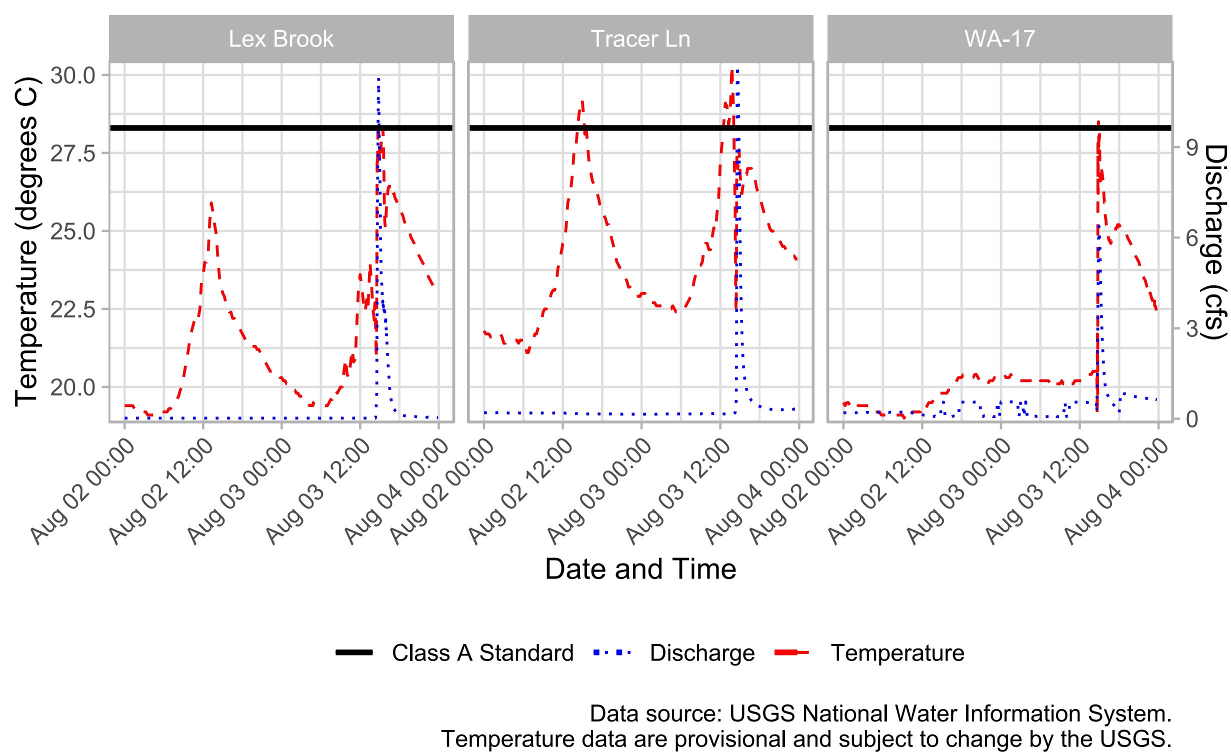


Figure 37: USGS temperature and corresponding runoff at Lex Brook, Tracer Ln, and WA-17 on August 2 and 3, 2018

Table 26: Warm water tributary temperature statistics, USGS continuous probe data, through 2018

Site Name	USGS Station ID	Period of Record	Maximum Temperature (°C) 2018	Maximum Temperature (°C) All Years	# Days > 28.3°C 2018	# Days > 28.3°C Max Year	Years with exceedances
HB @ Mill St	01104405	Nov. 2011 – Dec. 2018	24.2	27.4	0	0	none
Salt Depot	01104410	Nov. 2015 – Dec. 2018	27.4*	27.4	0	0	none
Lex Brook	01104415	Oct. 2007 – Dec. 2018	**28.5**	**28.5**	1	1	2018
Tracer Ln	01104420	Mar. 2012 – Dec. 2018	**32**	**32**	9	9	2016, 2018
HB Below Dam	01104430	Oct. 2007 – Dec. 2018	26.8	27.6	0	0	none
WA-17	01104455	Oct. 2007 – Dec. 2018	**28.5**	**28.5**	1	1	2018
MBS	01104453	Oct. 2007 – Dec. 2018	24.9	**30.1**	0	4	2010, 2012, 2016
Summer St	01104475	Oct. 2007 – Dec. 2018	24.2	24.6	0	0	none

Bolded temperatures exceed the 28.3 degrees C warm water fishery standard. Max Year is the year with the most maximum daily temperature exceedances. USGS data for all sites in 2018 data included provisional data subject to revision. Data were also provisional in 2016 and 2017 at HB Below Dam, Tracer Ln, MBS, WA-17, and Summer St.

*Provisional data showed that the maximum daily temperature exceeded 28.3 degrees C on September 6, 2018. However, the gage height fluctuated daily during this period, despite dry weather. This suggested that the stream bed was dry. Therefore, this temperature maximum was not considered an exceedance.

Tracer Ln also exceeded 28.3 degrees C on August 3rd as well as the prior day, August 2nd (Figure 37). Unlike Lex Brook and WA-17, the temperature exceedances at Tracer Ln occurred prior to the storm event. In addition, Tracer Ln exceeded 28.3 degrees C on July 15th through July 17th when maximum air temperatures were nearly 90 degrees F and on September 3rd through 6th when air temperatures were greater than 90 degrees F (Figure 13 and Figure 38). In total, maximum daily water temperatures at Tracer Ln exceeded 28.3 degrees C on nine occasions between July and September in 2018, the most of any site continuously monitored by the USGS (Table 26). Prior to 2018, the only exceedances observed by the USGS at Tracer Ln occurred during July, August, and September of 2016 during the drought, also for a total of nine times (Table 26). Low flow and stagnant water likely helped elevate water temperatures.

Despite these exceedances, daily maximum water temperatures recorded by the USGS continuous stations have never exceeded 28.3 degrees C more than 11 times from June through September, a threshold listed in the DEP 2016 CALM manual for determining whether a river meets the Aquatic Life use (Table 26). As such, these results suggest that warm water tributary temperatures in the Cambridge watershed supported the Aquatic Life use in 2018 and in previous years. However, if climate change leads to more frequent drought or warmer summers, tributaries such as Tracer Ln could be at risk of becoming unacceptably warm during the summer months.

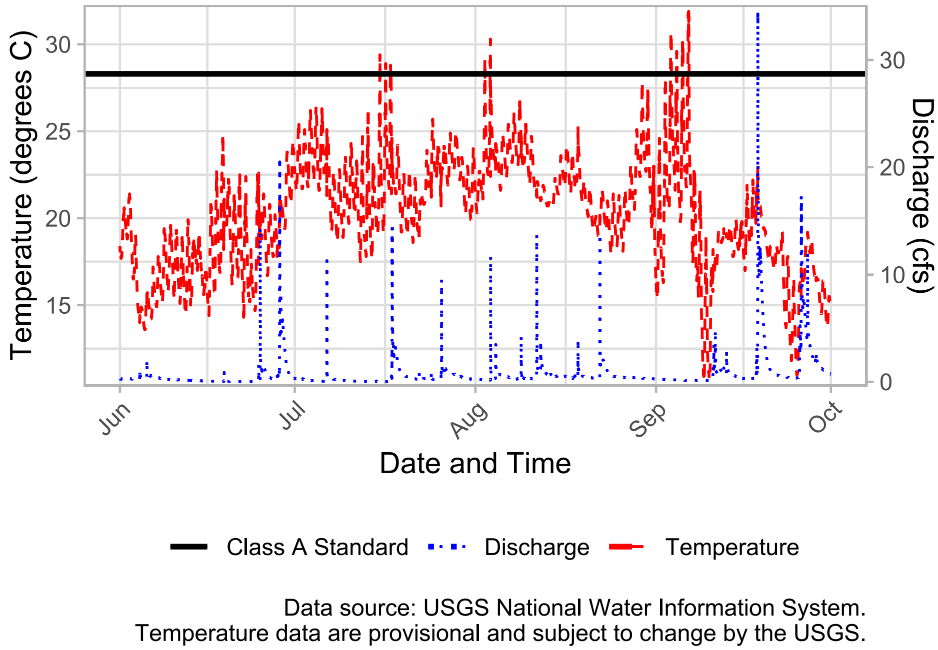


Figure 38: USGS Water Temperature and Discharge at Tracer Ln (station 01104420), June through September of 2018

CWD and USGS also monitored two CFR sites: SB @ Viles and RT 20. Temperatures at these sites were compared against the CFR Class A standard defined as 20 degrees C for the 7-DADM temperature unless naturally occurring. Discrete temperature readings collected by CWD exceeded 20 degrees C during one visit at each CFR site in 2018; CWD recorded a temperature of 20.51 degrees C on August 20th at SB @ Viles and 21.2 degrees C at RT 20 on July 12th (Figure 36).

To better assess CFR temperatures against the Class A standard, CWD calculated the rolling 7-DADM temperature using continuous USGS data from monitoring stations 01104370 (SB @ Viles) and 01104460 (RT 20). The 7-DADM temperatures at both sites frequently exceeded 20 degrees C in 2018, although the period of the elevated water temperatures was more extensive at RT 20 than at SB @ Viles (Figure 39 and Figure 40). SB @ Viles exceeded the Class A standard 72 times in 2018 compared to 109 exceedances at RT 20 (Figure 39 and Figure 40). The 2018 exceedances at SB @ Viles began in late June and lasted until early September whereas the 7-DADM temperatures at RT 20 began exceeding 20 degrees C in mid-June and remained elevated through mid-September (Figure 40).

These 2018 exceedance rates were aligned with historic exceedance frequencies (Figure 39). At SB @ Viles, annual exceedance frequencies of the 20 degree 7-DADM temperature standard ranged from 49 to 97 over the period of record (2010 – 2018). The range of exceedance frequencies was slightly higher at RT 20, spanning from 57 to 121 between 2008 and 2018. Unless naturally occurring, these exceedance frequencies are much higher than the 11 exceedances "allowed" in the DEP CALM methodology and suggest that the temperatures could prevent the CFR tributaries from meeting their Aquatic Life use. Potential reasons for the elevated temperatures include: heated runoff from pavement in the watersheds, releases of water from upstream impoundments, and loss of riparian vegetation.

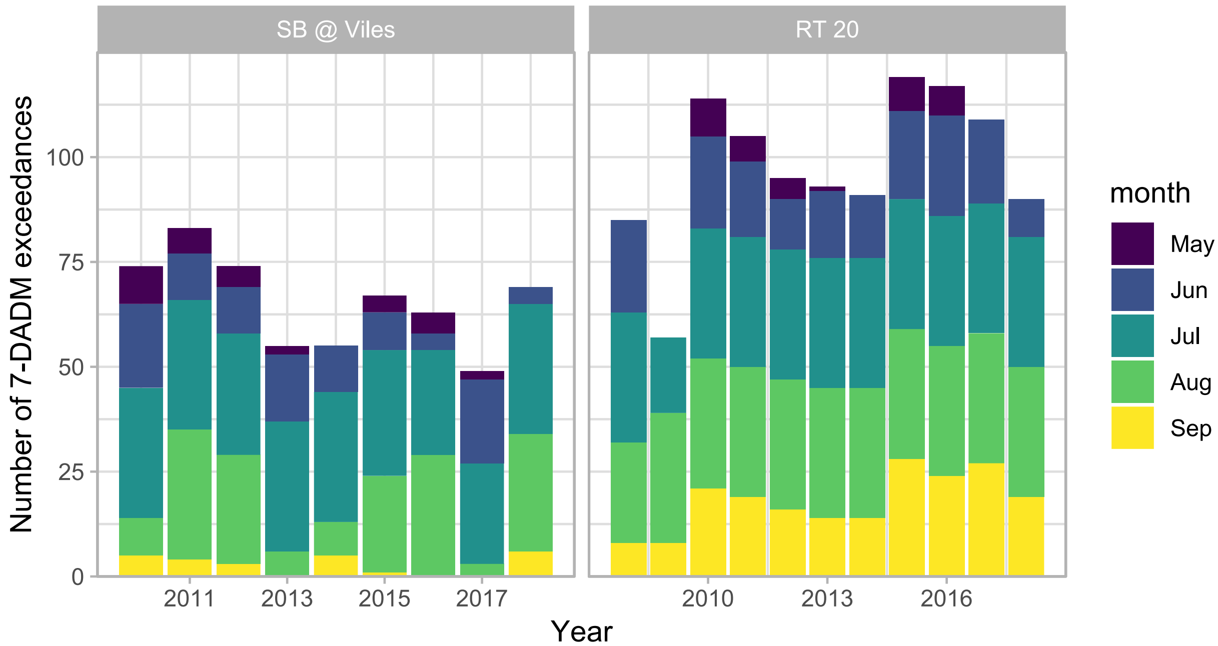


Figure 39: Annual seven-day average daily maximum temperature (7-DADM) exceedance frequencies of the 20 degrees C Class A CFR temperature standard, by month, calculated with USGS continuous temperature data, SB @ Viles (01104370) and RT 20 (01104460)

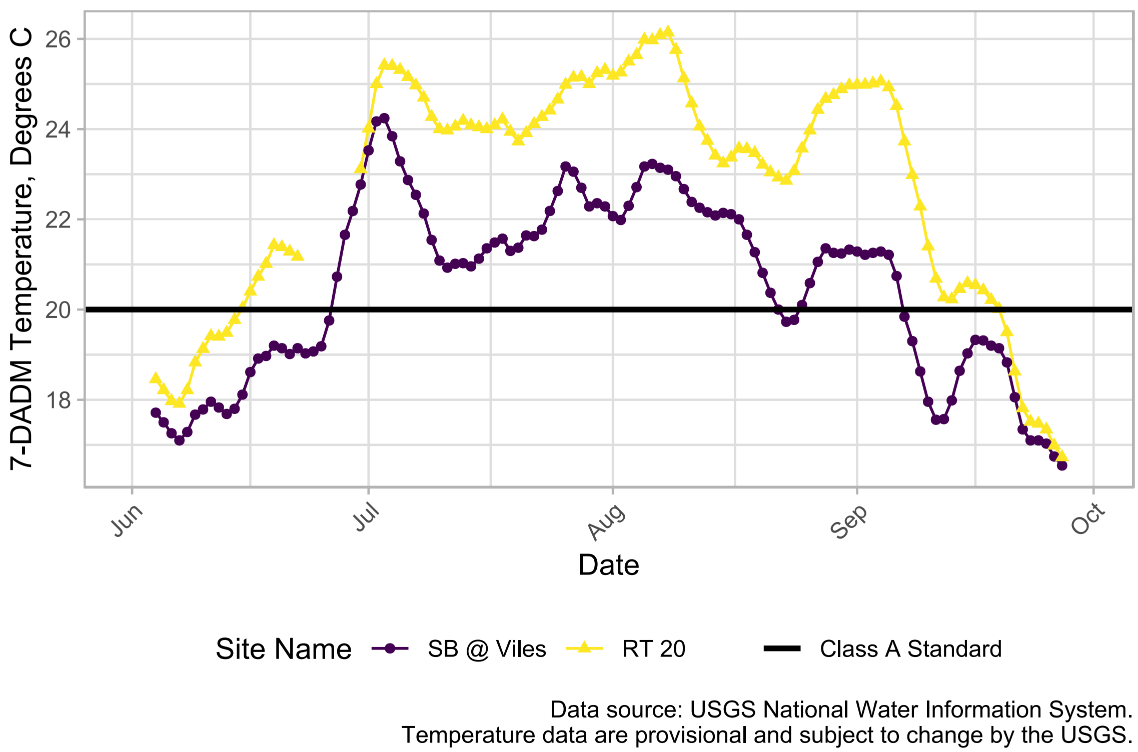


Figure 40: 2018 Seven Day Average Daily Maximum (7-DADM) Temperatures at SB @ Viles (USGS station 01104370) and RT 20 (USGS station 01104460)

To determine whether the temperature exceedances at SB @ Viles and RT 20 were naturally occurring, CWD followed the 2016 CALM natural condition evaluation method for small watersheds (<25 mi^2) (Massachusetts Division of Watershed Management Watershed Planning Program, 2016). Under this framework, exceedances may be naturally occurring if natural land and impervious cover meet the requirements in Table 27 and no other thermal sources exist, such as upstream impoundments or wastewater treatment plants. The land use thresholds in Table 27 must be met for both the entire tributary catchment area and the 100-meter stream buffer zone. Using the Land Cover/Land Use (2016) and MassDEP Hydrography (1:25,000)[10] datasets from MassGIS, CWD calculated the amount of natural land and impervious cover in the RT 20 and SB @ Viles watersheds and the 100-meter stream buffers. For the purposes of this analysis, the water and wetlands categories described in Table 1 were included with natural land.

Based on these results, temperature exceedances at RT 20 and SB @ Viles were not due to naturally occurring conditions. Natural land within both watersheds accounted for less than 80 percent of the drainage area and impervious cover was greater than 4 percent (Table 28). Likewise, natural land fell short of the 90 percent minimum in both 100-meter buffer zones where impervious cover also exceeded 2 percent.

Table 27: DEP CALM 2016 landscape criteria used to evaluate thermal excursions

Land Cover Type	Entire Watershed (%)	100-meter Stream Buffer (%)
Natural Land	>80%	>90%
Impervious Cover	<4%	<2%

Table 28: SB @ Viles and RT 20 catchment and 100-meter stream buffer zone land cover analysis

Extent	Category	SB @ Viles	RT 20
Complete Watershed	Area (mi^2)	10.4	22.0
	Natural Land (%)	78.1	72.9
	Impervious Cover (%)	8.3	14.0
100-meter stream buffer	Area (mi^2)	6.27	12.9
	Natural Land Cover (%)	83.2	79.0
	Impervious Cover (%)	5.9	10.5

9.3 Dissolved Oxygen (DO)

HB @ Mill St, Tracer Ln, and MBS were the only three sites to drop below the minimum Class A DO concentration of 5 mg/L for warm water fisheries in 2018 (Figure 41). At HB @ Mill St, the DO dropped below 5 mg/L in June (Figure 42). The water at HB @ Mill St was very turbid and backed up in June due to backflow from high reservoir levels. The site is downstream of a wetland and a beaver dam, which export organic matter. Oxygen in the standing water was likely consumed during the decomposition of the organic matter and was unable to sufficiently replenish due to lack of inflow. Similarly, MBS is downstream of a beaver pond, which was rich in organic matter. DO readings from June to October were less than 5 mg/L, presumably due to the high organic matter load (Figure 42). DO levels at Tracer Ln were below the

[10] The MassDEP Hydrography (1:25,000) used in this analysis was last updated on December 19, 2019

standard in June, August, and December. Tracer Ln was also downstream of a wetland and lies adjacent to I-95. Both the wetland and the highway may have been sources of organic matter, sediment, and nutrients which may have contributed to the low DO. Neither of the CFR sites (SB @ Viles and RT 20) had DO concentrations below the 6 mg/L Class A standard as measured by CWD in 2018 (Figure 41).

According to CWD data collected from 2000 through 2018, DO levels were often less than 5 mg/L at MBS and Tracer Ln during the summer and early fall (Figure 42). DO concentrations less than 5 mg/L were rare at HB @ Mill St. However, the beaver dam upstream of the monitoring station, first observed during the June 2018 visit, may result in more instances of low DO in the future. DO concentrations at all other sites were usually greater than the Class A minimum concentrations, with concentrations for the median and 90th monthly percentiles higher than the warm water fishery or CFR Class A minimum standard (Figure 42).

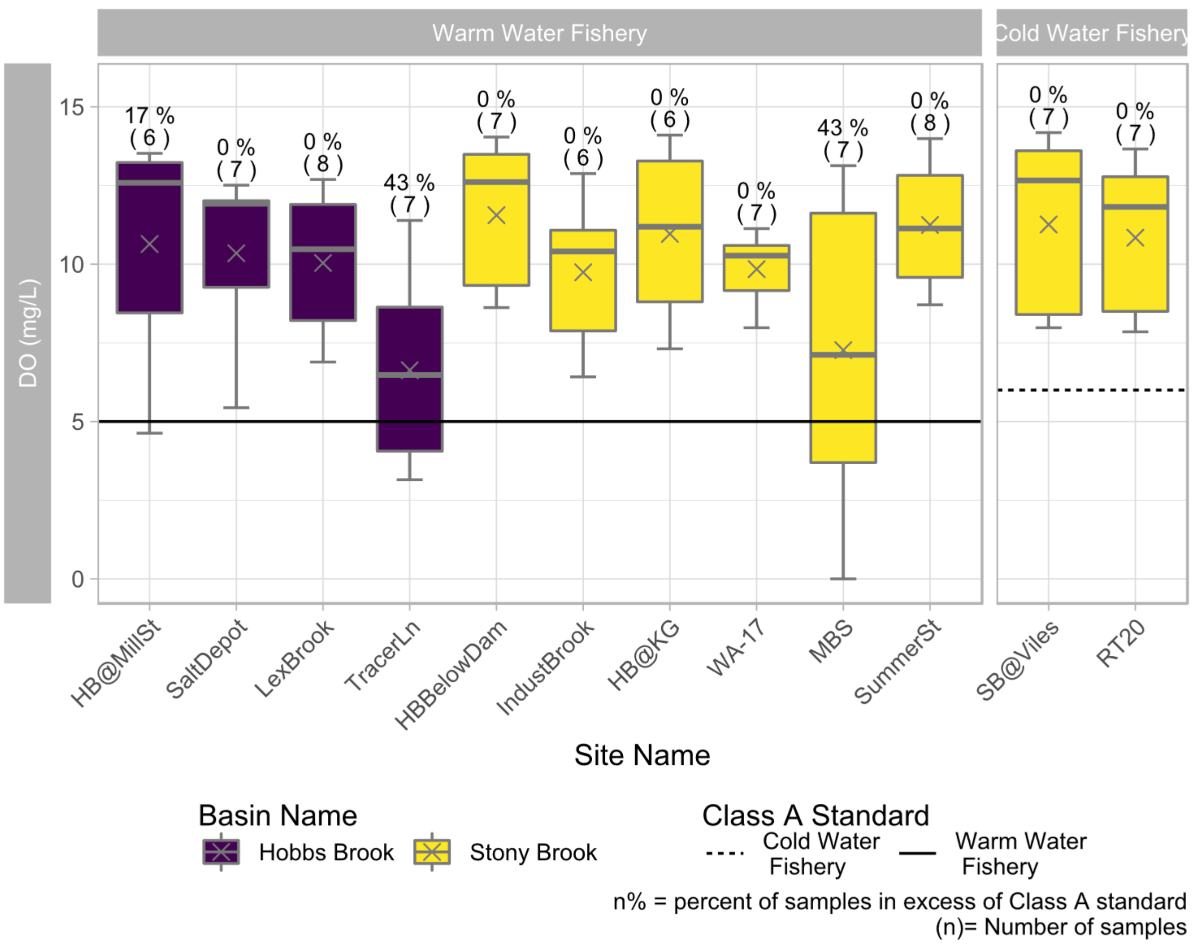


Figure 41: Tributary base-flow dissolved oxygen (DO), 2018

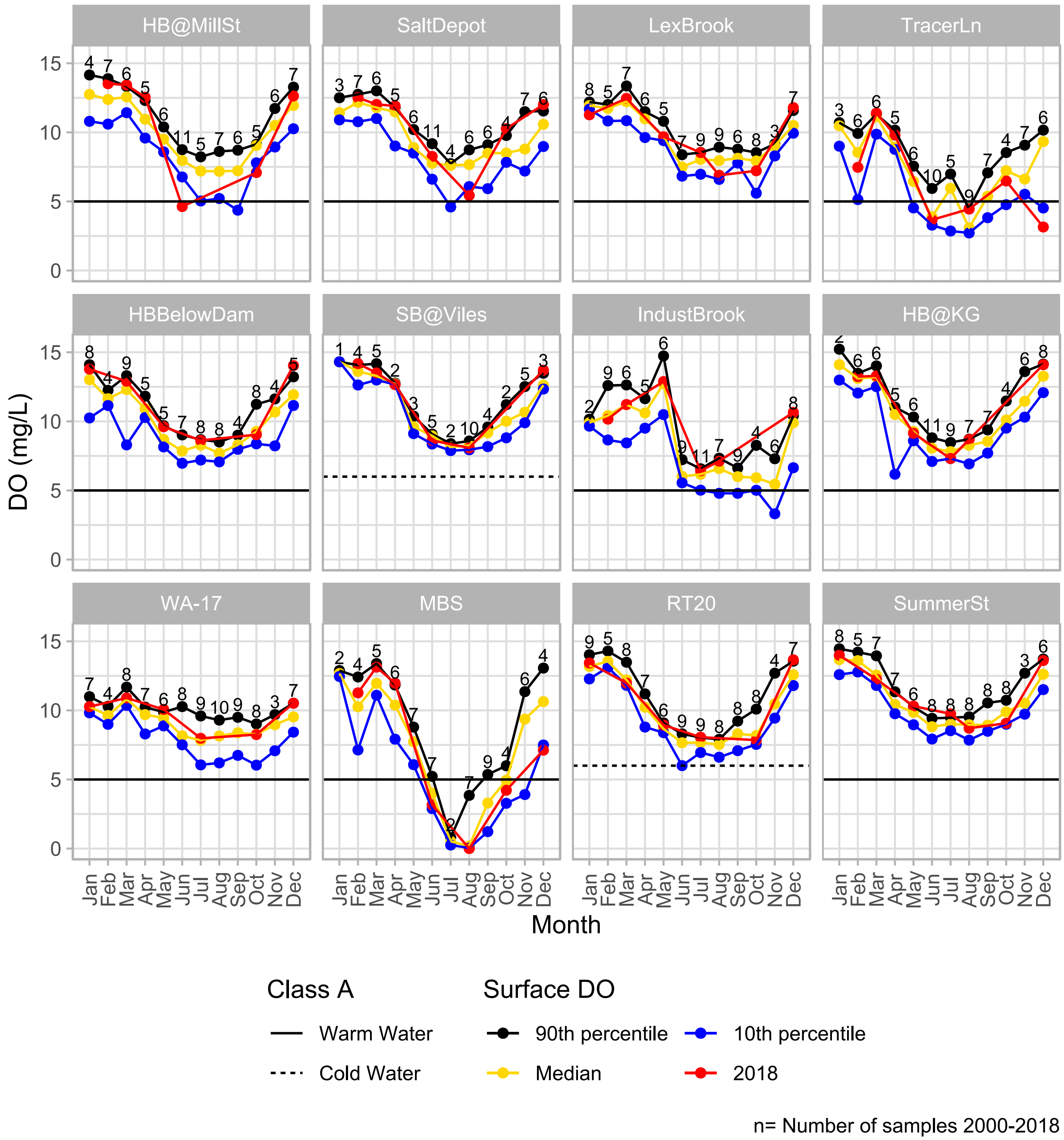


Figure 42: Tributary base-flow dissolved oxygen (DO) by month, 2000-2018

Although CWD recorded DO concentrations in 2018 below the Class A minimum for the Aquatic Life use at HB @ Mill St, Tracer Ln, and WA-17, discrete DO datasets must contain at least three to five measurements collected pre-dawn during the summer months in order to confirm that a river met the Aquatic Life use (Massachusetts Division of Watershed Management Watershed Planning Program, 2016). Sampling in the CWD program typically occurred between 9:00 am and 12:30 pm and the USGS did not collect continuous DO data at these tributary sites. As such, CWD DO data did not to conform to the DEP CALM sampling timeframe requirements so it is difficult to draw definitive conclusions about the Aquatic

Life use and DO. However, based on historical discrete DO data, oxygen depletion with the potential to harm aquatic life was most likely to have occurred at MBS, where DO regularly falls below 5 mg/L in the summer months (Figure 42).

9.4 BACTERIA

Similar to the reservoirs, tributary *E. coli* water quality results were compared against the Class A single sample 235 MPN/100 ml standard to determine whether tributaries were safe for primary contact recreation. Because *E. coli* samples were collected fewer than five times during the April 1st – October 15th bathing season, results were not compared against the 126 colonies/100 ml geomean standard recommended in the DEP CALM manual.

In 2018, *E. coli* results were lowest at the outlet of Hobbs Brook Reservoir (HB Below Dam) (Figure 43 and Table 29). *E. coli* in samples taken from Indust Brook had the highest median value (257 MPN/100 ml). In the Hobbs Brook Reservoir basin, 14% of samples (1 of 7) exceeded the standard at HB @ Mill St and Lex Brook. About one third (2 of 7) samples exceeded the standard at Salt Depot. In the Stony Brook Reservoir basin, 50% of the samples at Indust Brook exceeded the standard, along with one sample each from HB @ KG and MBS. These exceedances could be the result of septic system leachate or leaking sewer lines. The exceedances could also be due to animal sources, such as geese and beavers. HB @ Mill St and MBS were among the least developed catchments in the Cambridge watershed, but had active beaver populations near the sampling locations. Despite exceedances of *E. coli*, median concentrations only exceeded the standard at Indust Brook.

Table 29: Tributary base-flow E. coli results (MPN/100 ml), 2018

Site Name	**Calendar Year 2018**						
	n>235	**n**	**%**	**Min**	**Max**	**Median**	**Mean**
HB @ Mill St	1	7	14	5	**291**	28	69
Salt Depot	2	7	29	4	**866**	24	197
Lex Brook	1	7	14	15	**248**	68	79
Tracer Ln	0	7	0	7	210	21	69
HB Below Dam	0	7	0	1	17	1	3
SB @ Viles	0	6	0	15	201	25	58
Indust Brook	3	6	50	3	**517**	**257**	**250**
HB @ KG	1	6	17	2	**921**	29	178
WA-17	0	7	0	18	154	42	69
MBS	1	7	14	1	**291**	7	51
RT 20	0	7	0	10	119	20	47
Summer St	0	7	0	1	214	15	43

n>235 = number of samples >235 MPN/100 ml, n=total number of samples, % = percent of samples >235 MPN/100 ml, Min=minimum, Max=maximum. Bolded statistics exceed the Class A criterion. Results less than the detection limit were set to the detection limit for the purposes of calculating statistics.

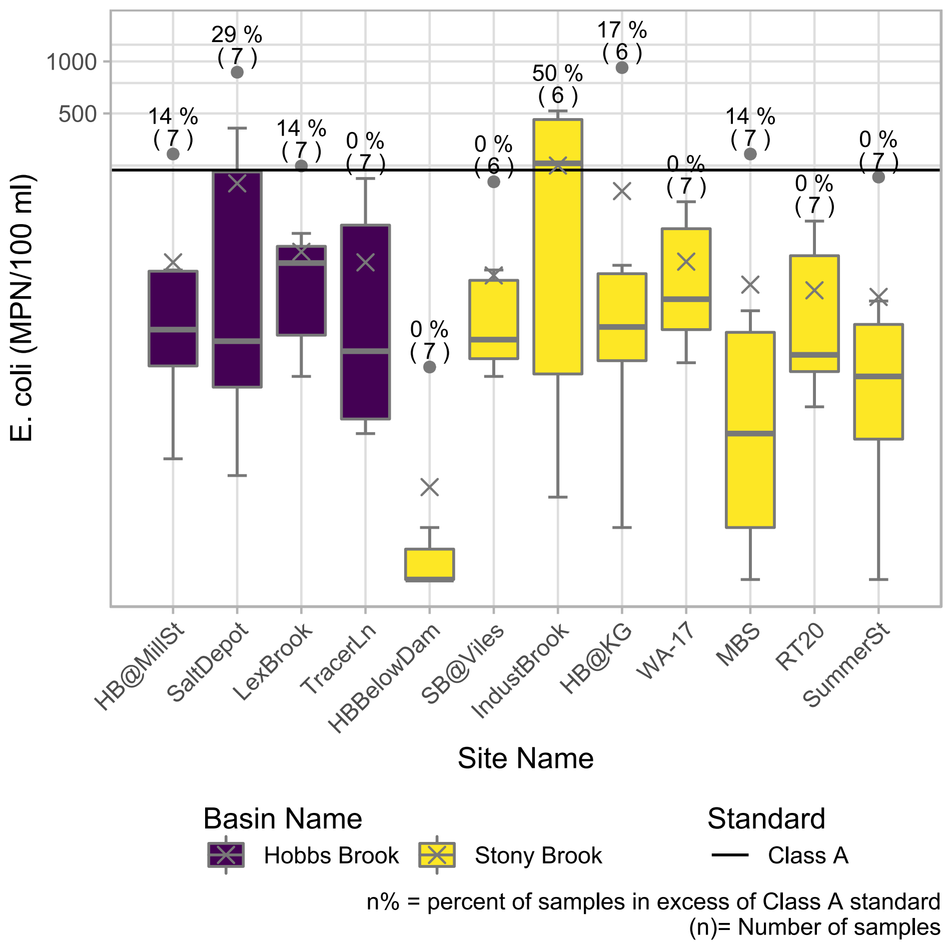


Figure 43: Tributary Base-flow E. coli, 2018

Despite the exceedances experienced in 2018, median concentrations were similar to previous years and did not appear to indicate a worsening water quality trend (Figure 44). Even though the 2018 median *E. coli* concentration at Indust Brook (257 MPN/100 ml) did exceed 235 MPN/100 standard for the first time since 2006, the median was only slightly higher than 2007 (200 MPN/100 ml) and may represent natural variation at the site. However, if *E. coli* levels continue to rise at Indust Brook, then further investigation will be performed to identify the cause. Regardless, the low *E. coli* levels at Hobbs Brook and Stony Brook Reservoirs (see Section 8.5) demonstrate that tributary exceedances were not significant enough to impair water quality downstream in the reservoirs.

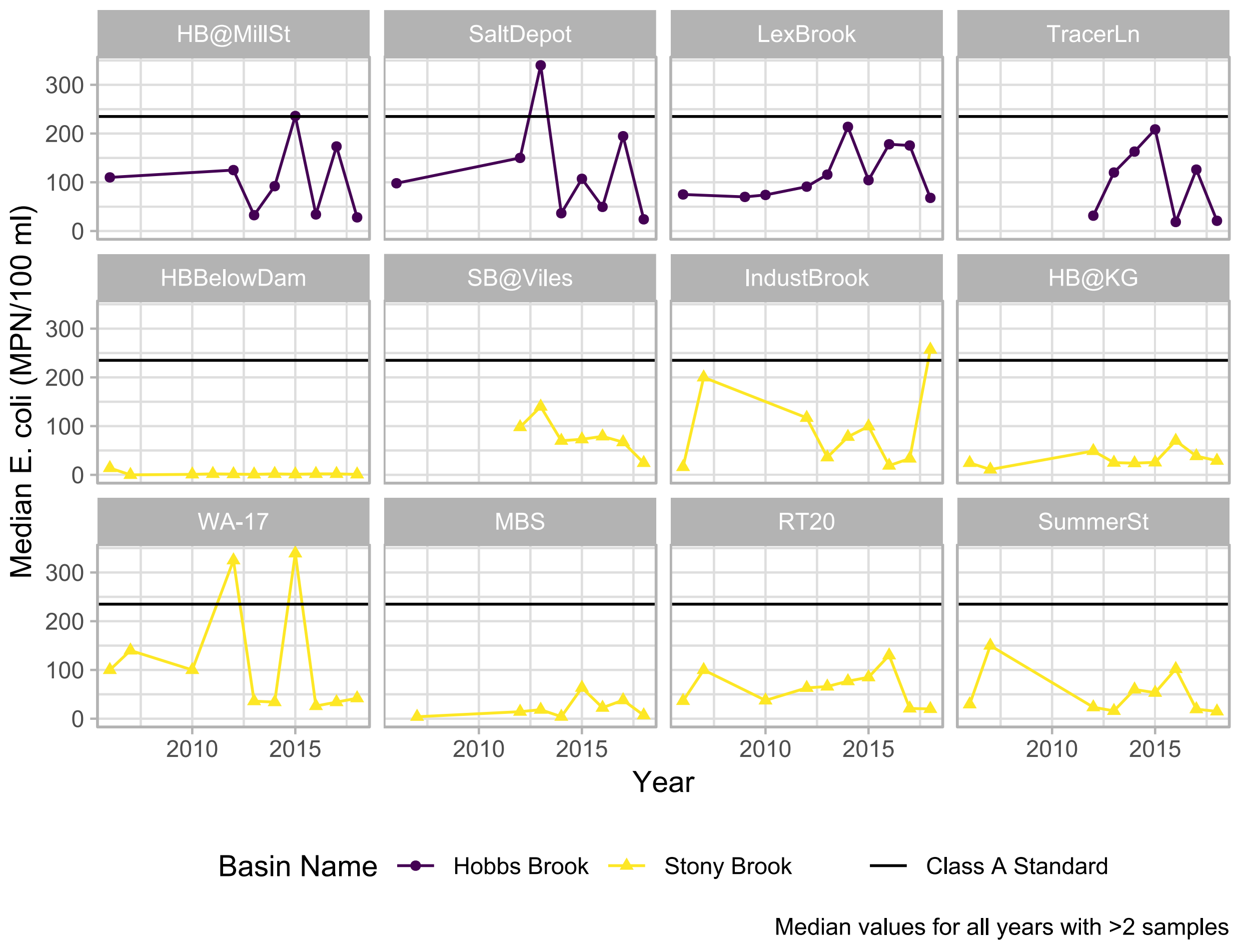


Figure 44: Median tributary E. coli levels, 2006-2018

9.5 Eutrophication

As with reservoirs, MA DEP relies on a host of different Primary Producer Biological and Physico-chemical Screening Guidelines to evaluate whether rivers and streams meet the Aquatic Life use for nutrients. In wadeable rivers such as the Cambridge watershed tributaries, MA DEP Screening Guidelines involve analysis of benthic and filamentous algae, benthic chl-*a* concentrations, diel fluctuations in DO saturation and pH, maximum pH levels, and TP concentrations. The TP guidelines are defined in the EPA Gold Book and apply to the mean TP concentration during the growing season, assuming a sample size of at least three. The CWD tributary monitoring program does not assess benthic algae nor does it include continuous DO and pH readings, although no discrete elevated pH levels (pH > 8.3) were observed during 2018. CWD does measure TP, but no site had the required three samples during the summer months. Given the mismatch in data collection programs, eutrophication of CWD tributaries were assessed in relation to the reference site nutrient concentrations defined by the EPA nutrient criteria.

Median 2018 TP concentrations at all sites except for Indust Brook were below the 0.02375 mg/L EPA nutrient criterion (Figure 45). However, every site except for HB Below Dam exceeded 0.02375 mg/L at least once in 2018. Sites located downstream of wetland systems, such as HB @ Mill St, Salt Depot, Tracer Ln, Indust Brook, WA-17, and MBS, may have been affected by the export of organic phosphorous from those systems. Despite being collected under base-flow conditions, inorganic sources of TP, such as roadway sediments settled in the stream, may still have contributed to the TP load.

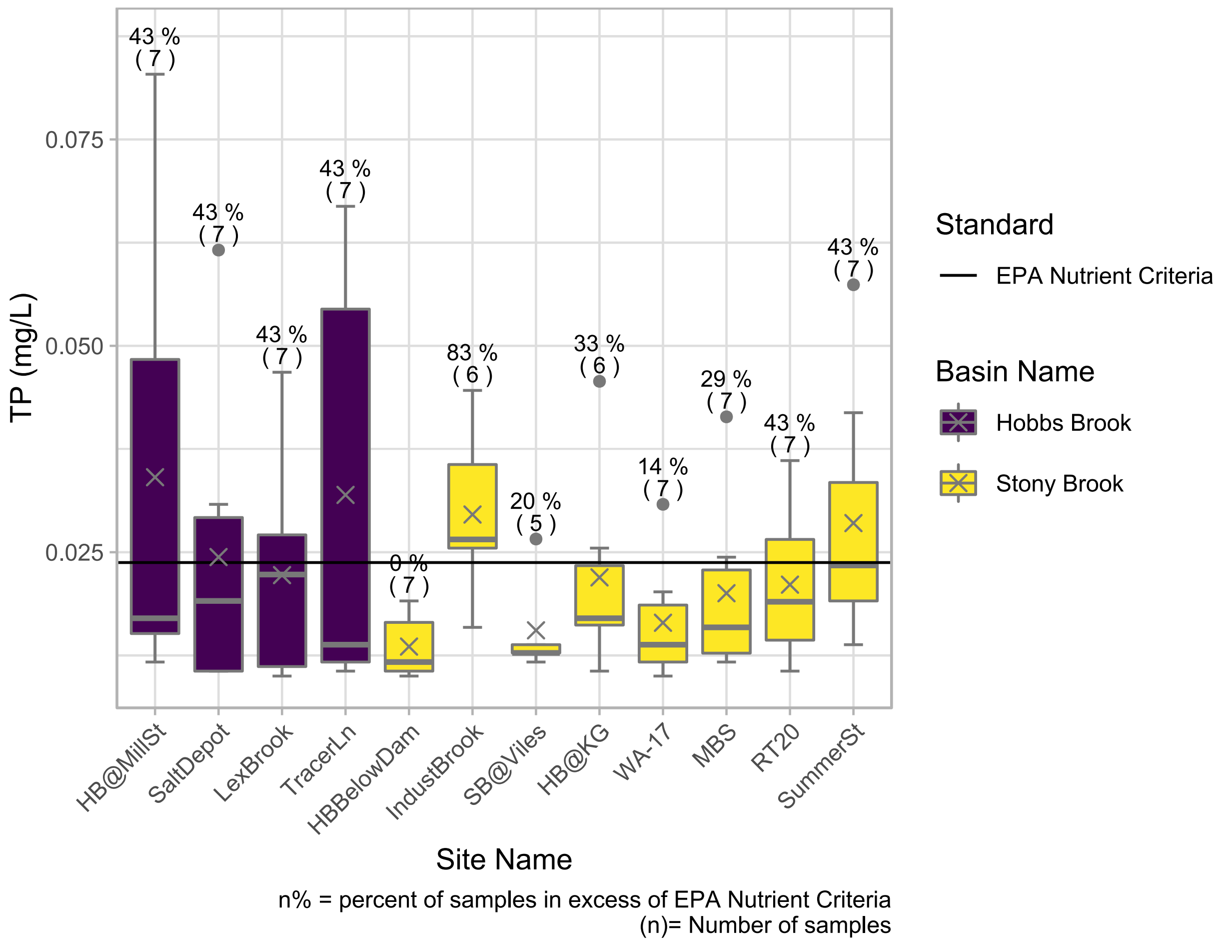


Figure 45: Tributary base-flow TP, 2018

Apart from Indust Brook and Salt Depot, the median turbidity values for all tributary sites were below the EPA nutrient criterion of 1.68 NTU (Figure 46). HB Below Dam, SB @ Viles, RT 20, and Summer St did not exceed this criterion during any base-flow sampling event in 2018. The remaining sites exceeded the standard at a rate of between 14 and 43 percent. Sediments from roadways and development activities may have added to turbidity at Indust Brook, although these sources would be expected to have a greater influence during stormflow sampling than during base-flow sampling. The low exceedance rates for TP and turbidity at HB Below Dam is likely attributable to settling of particles in the basin prior to discharge from the dam outlet.

TP and turbidity median concentrations have been relatively consistent since the beginning of the CWD monitoring program in 2000 and do not appear to show increasing or decreasing trends (Figure 47 and Figure 48). One exception is WA-17, where base-flow turbidity and TP spiked after the installation of a stormwater wet detention pond system upstream of the monitoring site in October of 2012 (Figure 49). This suggests that the system did not function as intended. This problem was discussed in detail in Section 7 of the 2017 Water Quality Report (CWD, 2019b). To remedy the situation, CWD coordinated with

MassDOT to install a diversion weir to prevent base-flow from entering the system, instead routing the flow directly to the WA-17 monitoring station. The weir was installed in late 2018 with the hopes of improving the conditions. Future monitoring efforts will determine whether this has happened.

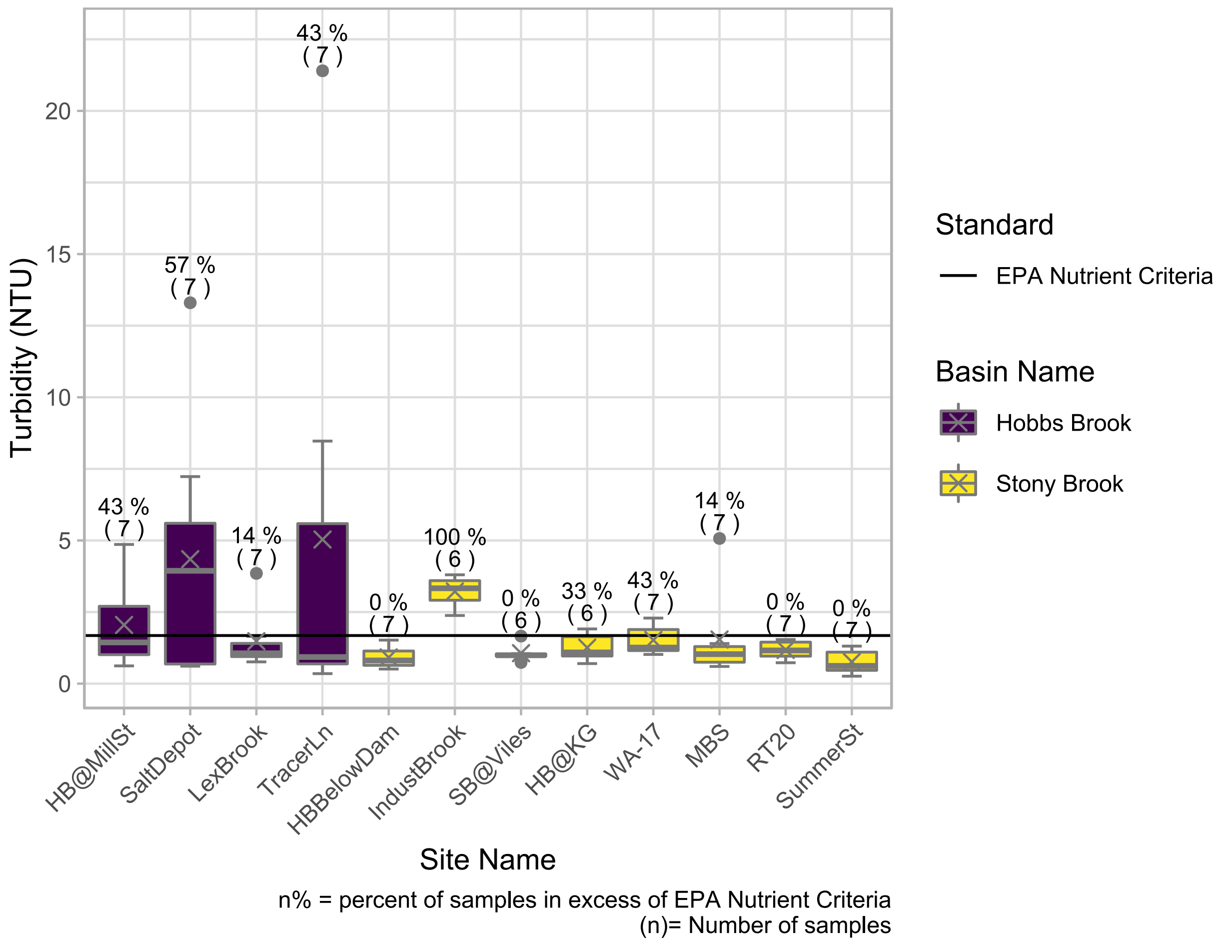


Figure 46: Tributary base-flow turbidity, 2018

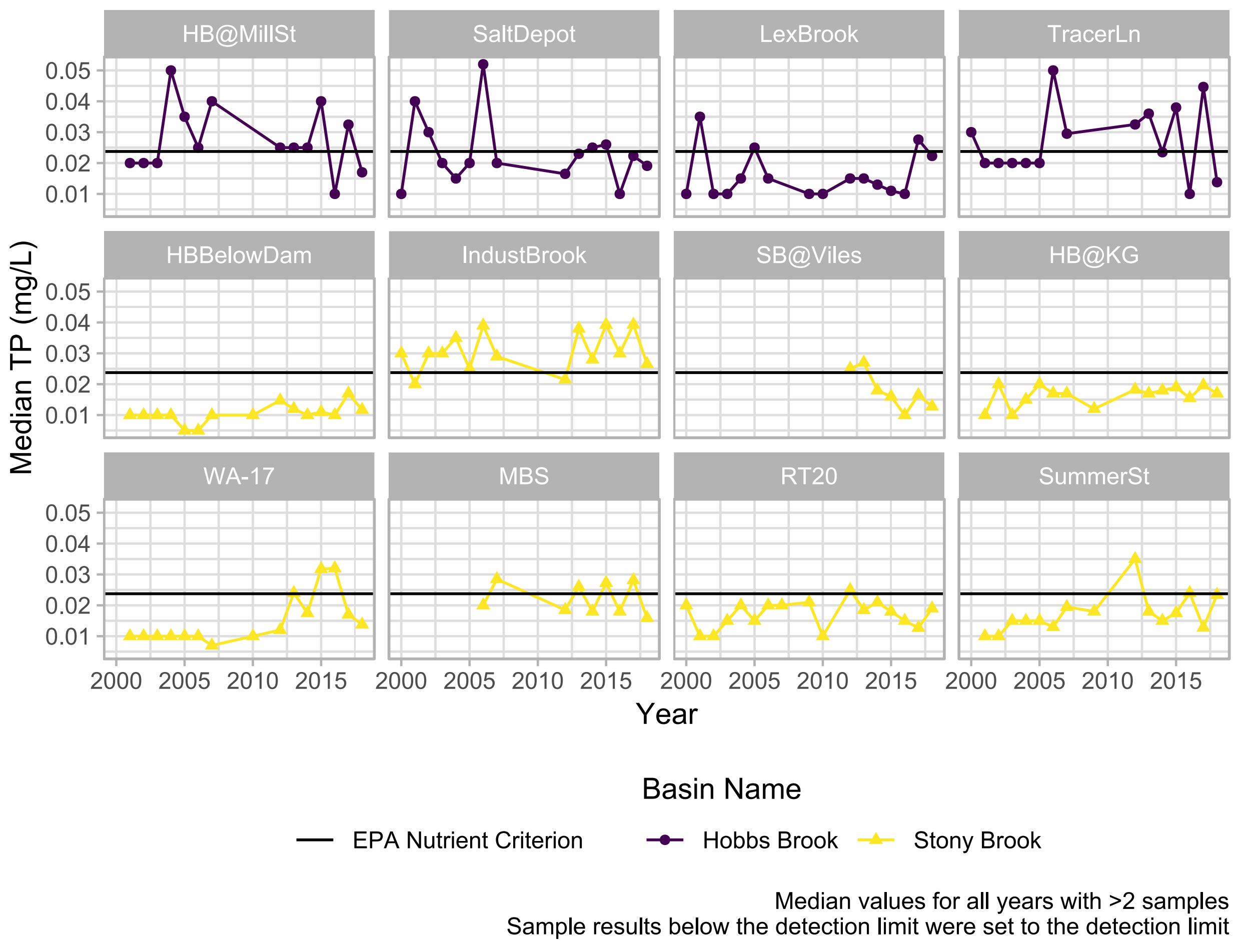


Figure 47: Tributary base-flow TP concentrations, 2000 - 2018

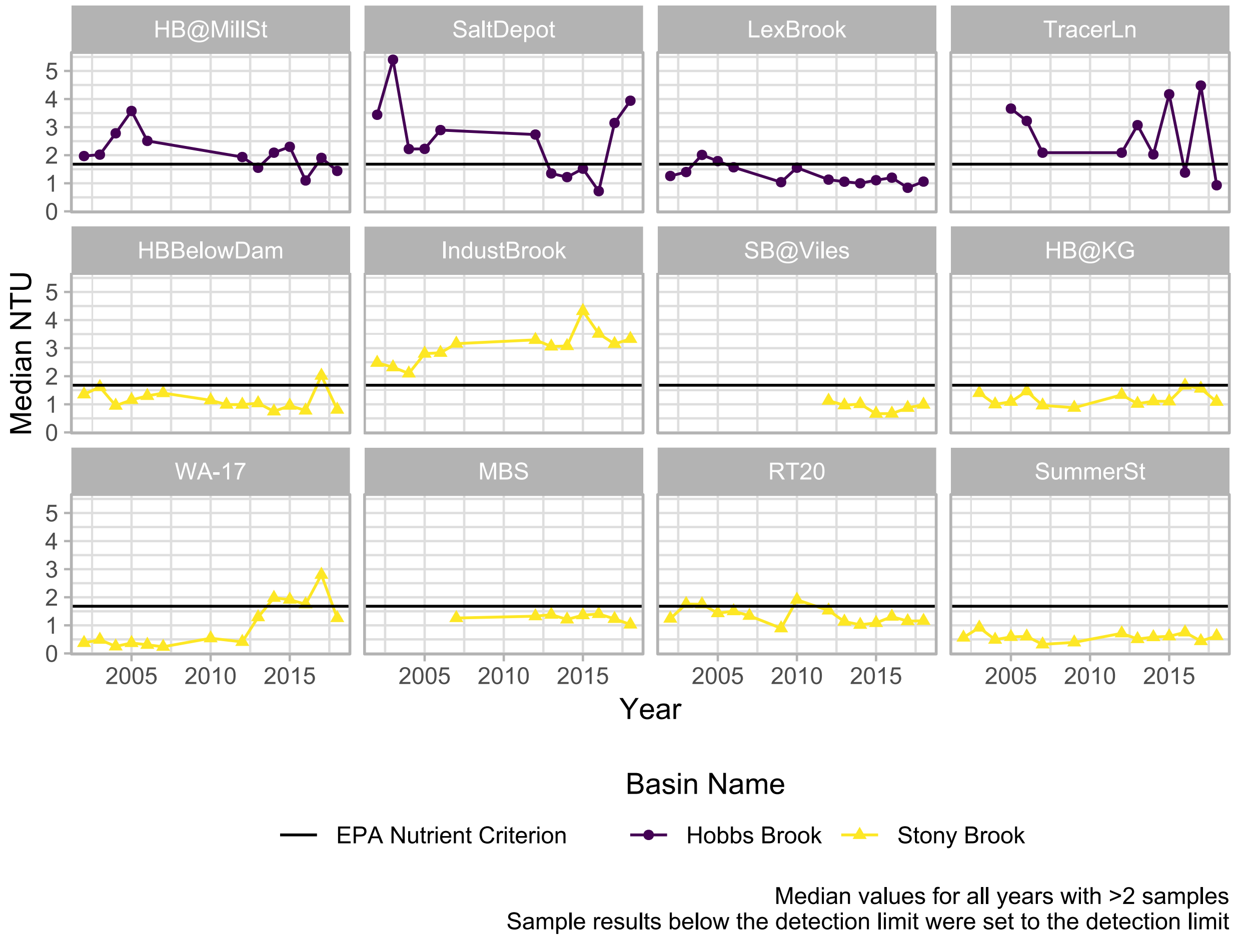


Figure 48: Tributary median base-flow turbidity (NTU), 2000 – 2018

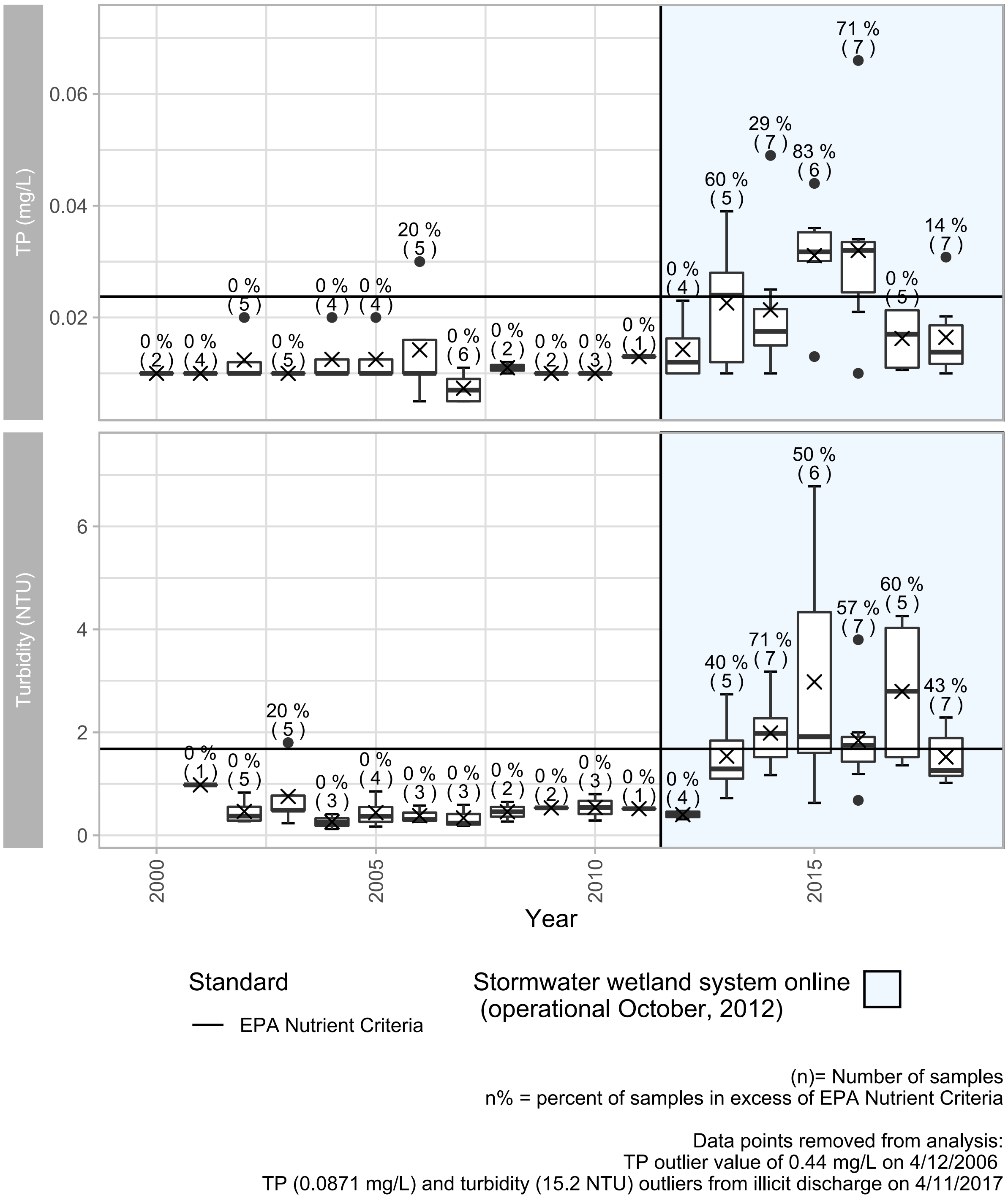


Figure 49: WA-17 base-flow TP and turbidity, 2000-2018

Although nitrogen is not believed to be a limiting nutrient in Cambridge reservoirs, CWD compared tributary nitrogen concentrations against reference conditions defined by the EPA nutrient criteria. TN is the sum of TKN (ammonia nitrogen and organic nitrogen) and nitrate and nitrite nitrogen. Median TN concentrations at all sites besides HB Below Dam and Salt Depot exceeded the EPA nutrient criterion of 0.61 mg/L in 2018 (Figure 51). Median concentrations at eight sites exceeded the 0.31 mg/L nitrate and nitrite nitrogen criterion (Figure 51). Summer St had the highest TN concentration of any tributary in the watershed (median = 2.06 mg/L), followed by WA-17 (median = 1.93 mg/L) and Indust Brook (1.49 mg/L). The TN concentrations at Summer St and WA-17 were primarily driven by nitrate and nitrite nitrogen concentrations and had the lowest median TKN concentrations of the tributaries, at 0.366 and 0.355 mg/L (Figure 50 and Figure 51). Indust Brook had the highest median TKN at 0.58 mg/L. None of the tributary sites had a median TKN concentration below the EPA nutrient criterion of 0.3 mg/L.

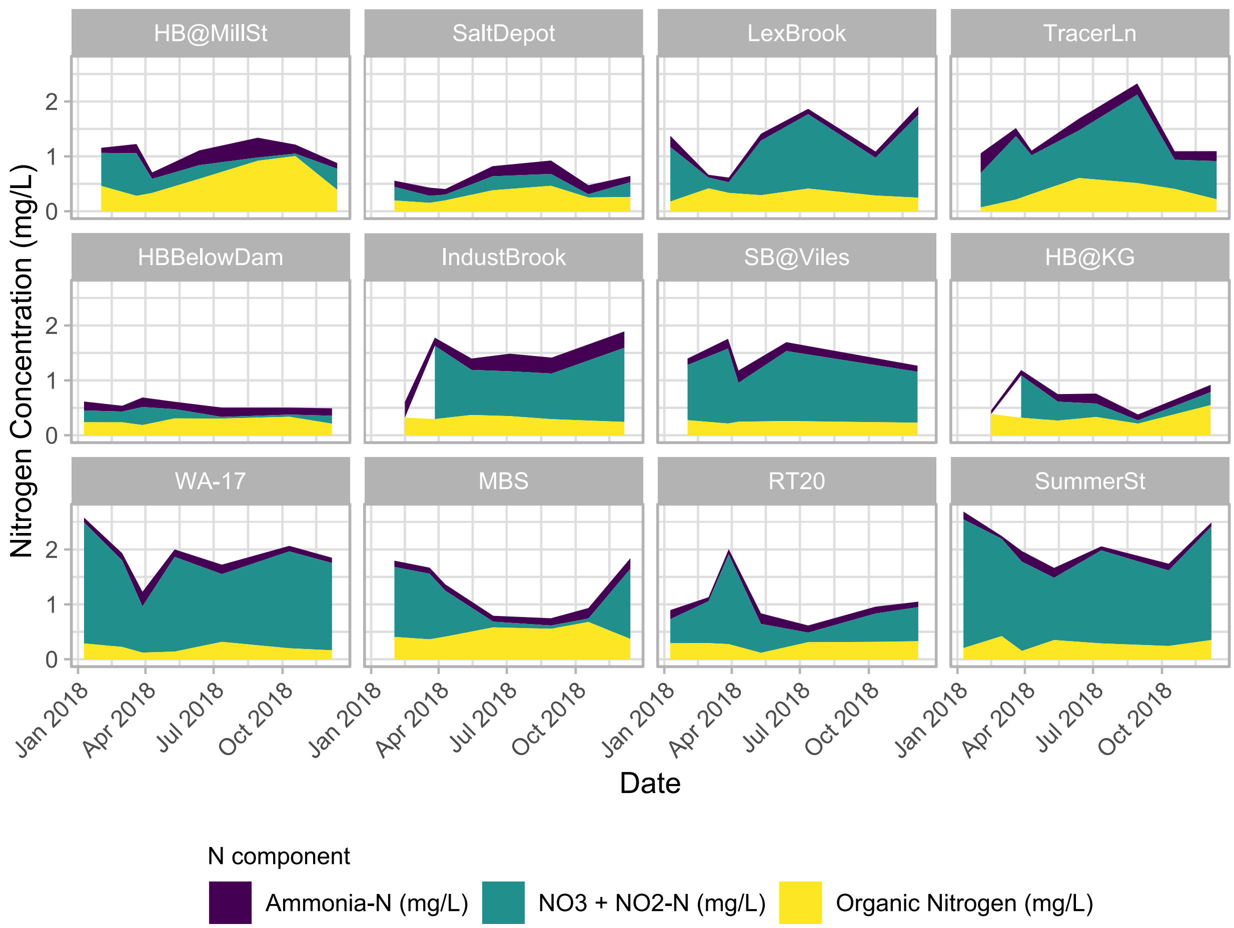


Figure 50: Tributary total nitrogen by species, 2018

TN concentrations have stayed consistent since 2000, except at WA-17 (Figure 52). TN at WA-17 increased following the 2012 installation of the stormwater basin, but eventually stabilized once vegetation established in the basin. Median TN concentrations then returned to baseline levels or lower, suggesting that the basin was functioning as a nitrogen sink.

Sources of nitrate and nitrite include fertilizers and solid sanitary waste effluent. Nearly 23 percent of the Summer St catchment was comprised of open space, much of which was a golf course (Figure 3 and Table 2). Fertilizer used on lawns and the golf course may have been sources of the elevated nitrogen. The catchment is also served by septic systems, another potential source of nitrate/nitrite nitrogen.

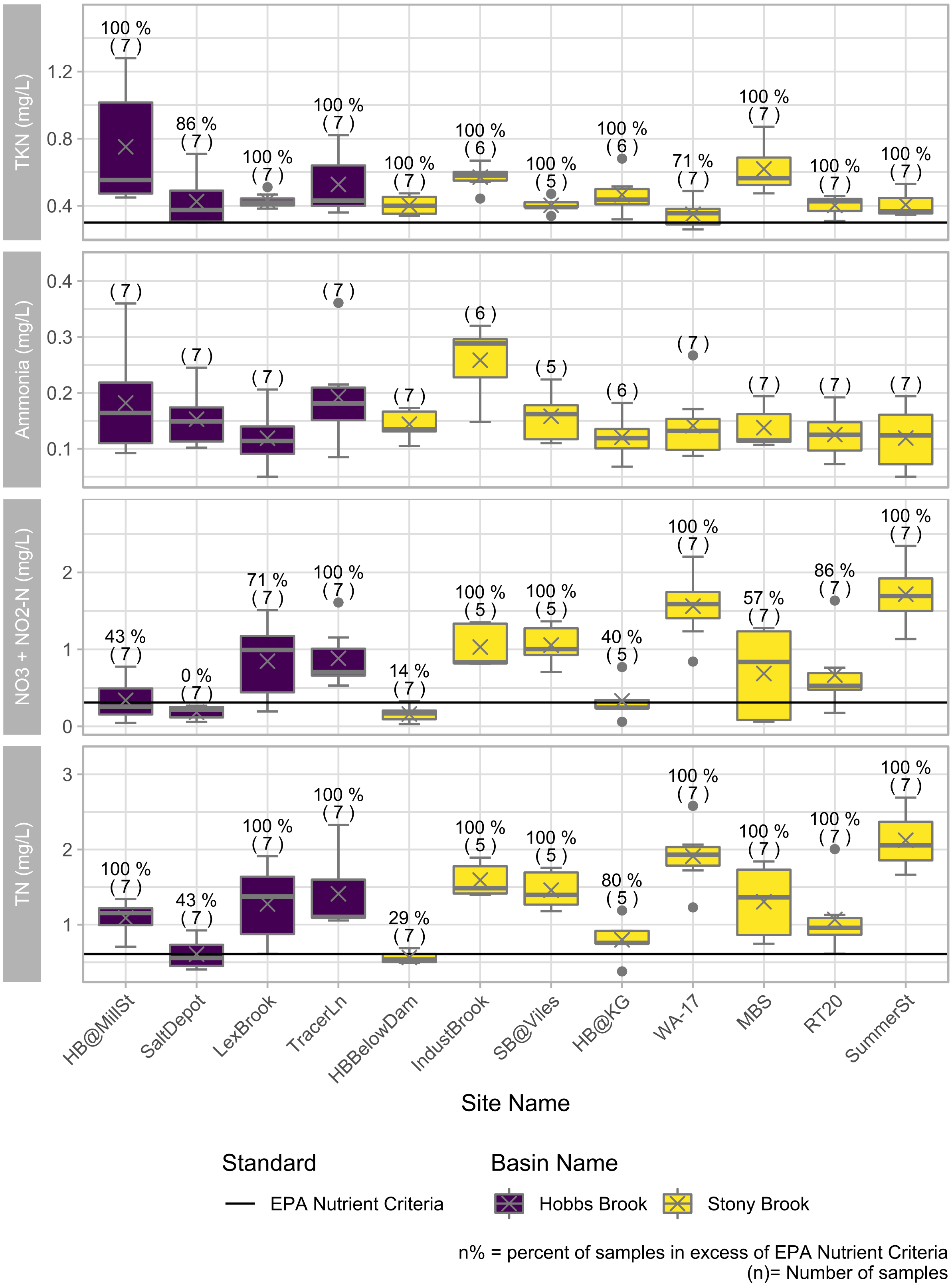


Figure 51: Tributary nitrogen concentrations, 2018

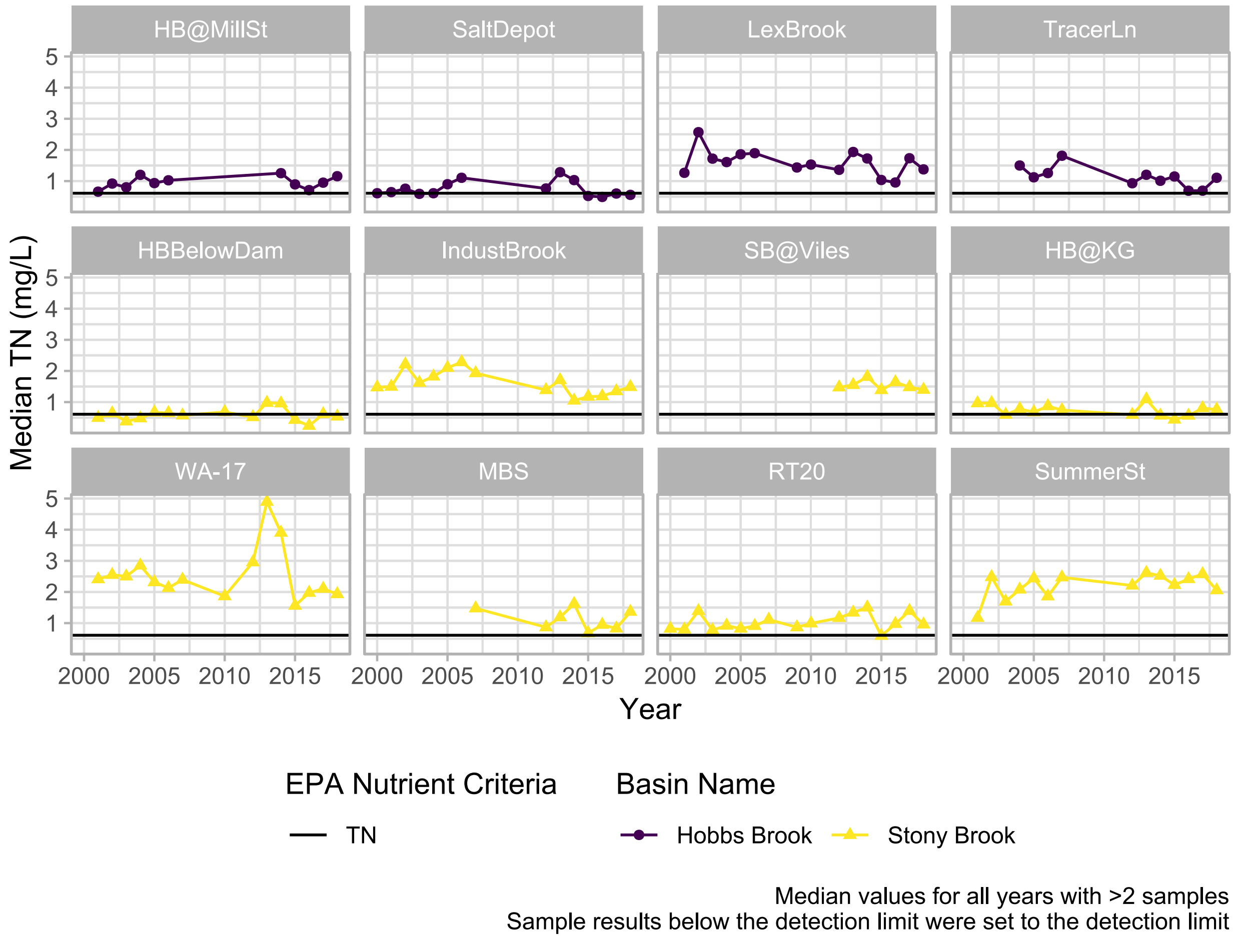


Figure 52: Tributary Median TN concentrations, 2000 – 2018

9.6 Iron and Manganese

Similar to the reservoirs, iron and manganese were compared against the SMCLs. SMCLs are voluntary guidelines set to avoid taste and odor issues for treated drinking water, although they provide a useful metric for evaluating ambient drinking water prior to treatment. Summer St had the lowest iron and manganese exceedance rates (33% and 17%, respectively) of all 12 tributary sites (Figure 53). SB @ Viles had the next lowest exceedance rate at 50 percent for both parameters (3 of 6 samples). Both sites had median values below the SMCLs for both parameters. HB Below Dam had a 29% exceedance rate for the iron SMCL and a median below the limit, but a 71% exceedance rate and a median above the SMCL for manganese. For MBS, the opposite was true with a 43% exceedance rate and a median below the SMCL for manganese, but an 86% exceedance and median above the SMCL iron, although just barely at 0.36 mg/L. All other sites exceeded the SMCL in 71 to 100 percent of samples in 2018. Outlier spikes in iron and manganese occurred at multiple tributary monitoring sites in 2018.

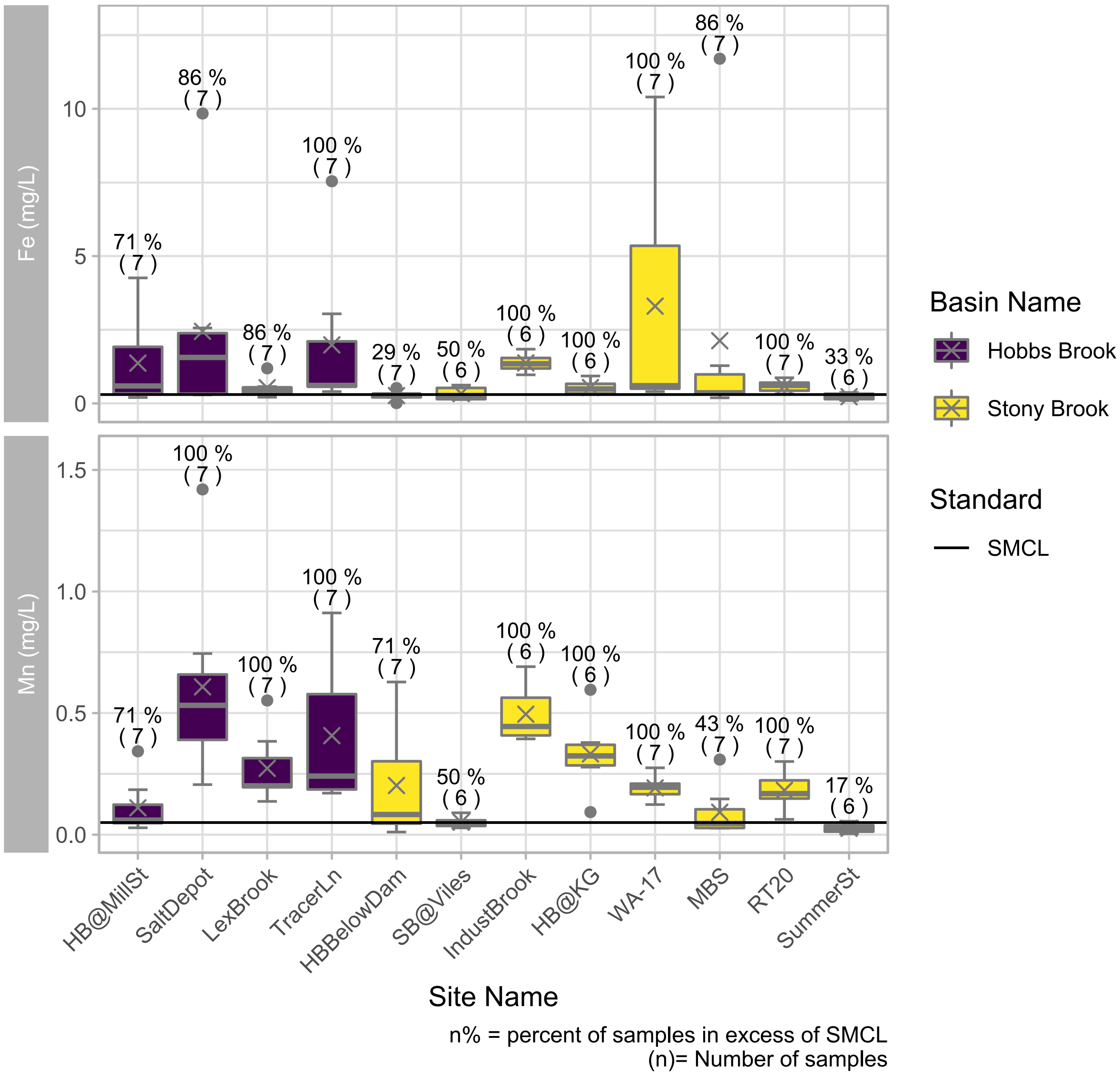


Figure 53: Tributary base-flow iron and manganese, 2018

Median concentrations appeared stable over time and did not indicate an increasing or decreasing trend, although median concentrations, particularly for iron, did appear to increase at WA-17 after the 2012 installation of the stormwater basin (Figure 54). This may have been due to warm, stagnant water in the malfunctioning treatment pond, which may have led to low DO conditions promoting the release of iron from sediments in the pond; the increase in median iron concentration in 2012 was coincident with increased median TP and turbidity concentrations (Figure 49 and Figure 54).

Although the Stony Brook Reservoir had the highest median concentrations of iron and manganese of the three reservoirs, tributaries in the Stony Brook basin did not have overall higher annual median concentrations than tributaries in the Hobbs Brook Reservoir basin (Figure 19, Figure 53, and Figure 54). Iron and manganese median surface concentrations in Hobbs Brook Reservoir and Stony Brook Reservoir were also generally lower than tributary median concentrations (Figure 19, Figure 53, and Figure 54). This indicates that reservoir concentrations of iron and manganese were more influenced by benthic bed sediment composition and biochemical reactions within the water bodies than by the iron and manganese concentrations from the contributing tributaries.

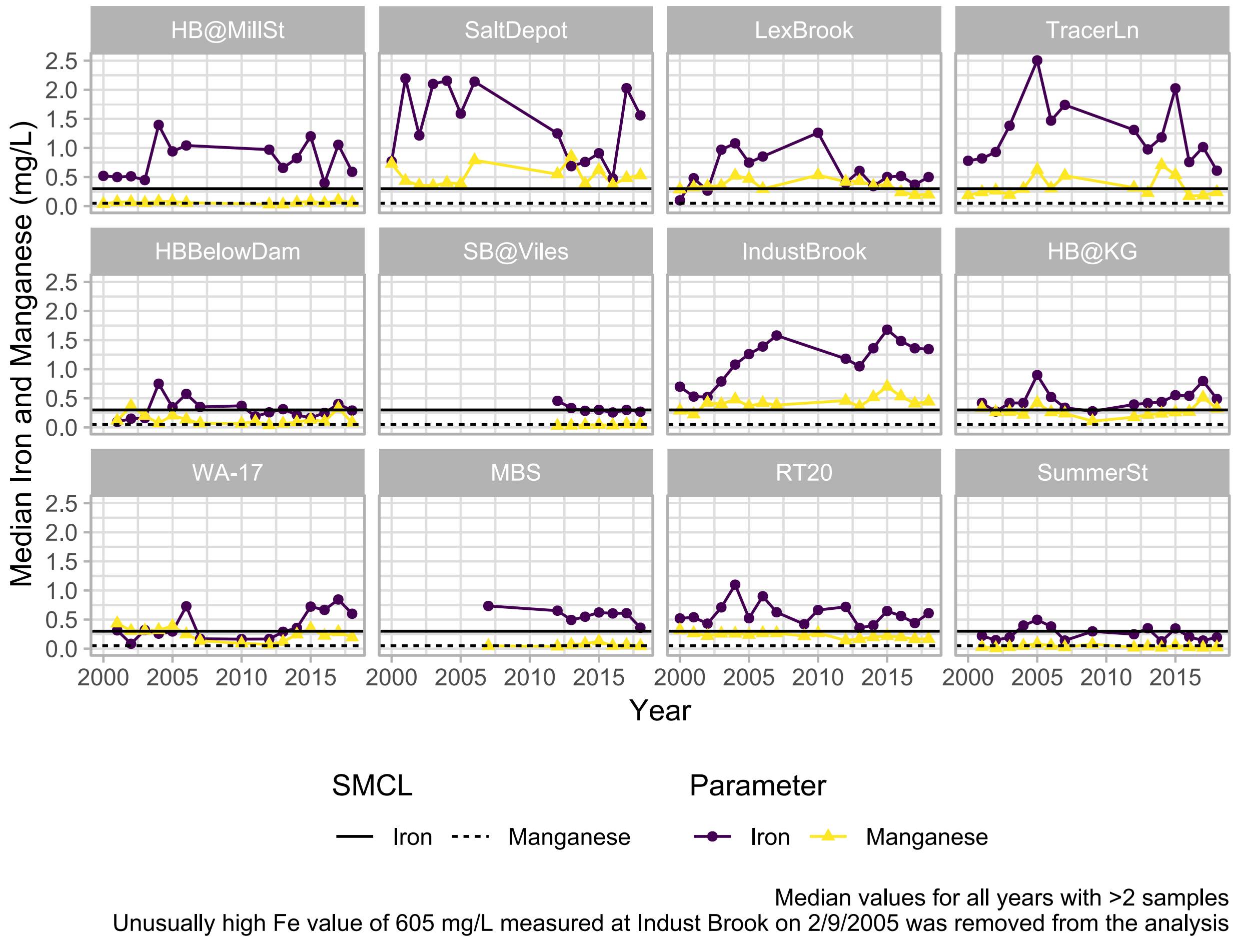


Figure 54: Tributary base-flow median iron and manganese, 2000-2018

9.7 Sodium and Chloride

Due to proximity to highways, roadways, and impervious surfaces, deicing salts have likely contributed to elevated concentrations of sodium and chloride in tributaries throughout the Cambridge watershed. In the USGS baseline study, sodium and chloride yields from tributary subbasins were positively correlated with the percent areal coverage of state-maintained roads, locally maintained roads, and all roads, with correlation coefficients ranging from r = 0.713 to r= 0.998 (Waldron and Bent, 2001).

Given the elevated sodium and chloride concentrations in the reservoirs, it was no surprise to see similarly elevated concentrations in the tributaries. Every sample collected by CWD in 2018 exceeded the sodium 20 mg/L ORS Guideline (Figure 55 and Table 30). Additionally, seven sites (Salt Depot, Lex Brook, Tracer Ln, HB Below Dam, Indust Brook, HB @ KG, and WA-17) had median chloride concentrations above both the 230 mg/L EPA chronic toxicity standard and the 250 mg/L SMCL (Figure 55 and Table 31). Indust Brook had by far the highest concentrations of sodium and chloride, with median concentrations of 495 mg/L and 838 mg/L, respectively, and was the only site with samples exceeding the 860 mg/L EPA acute toxicity standard. Indust Brook also had the highest percent of impervious cover (64.7 percent) in the watershed and had the fourth highest number of road miles per square mile of catchment area (17.1 mi/mi^2) (Table 3). Lex Brook, Tracer Ln, and WA-17 are adjacent to I-95 and Route 20, which likely explained the elevated salt concentrations at these sites. Even though Salt Depot receives minimal drainage from I-95, it still had an elevated median chloride concentration of 390 mg/L. This was presumably attributable to a historic groundwater salt plume resulting from uncovered, bare ground storage of sodium chloride by MassDOT, as well as potential spillage from highway deicing operations (Geotechnical Engineers Inc, 1985). Based on the chloride concentrations in relation to the EPA acute and chronic toxicity standards, these seven tributary sites may fall short of meeting the Aquatic Life use.

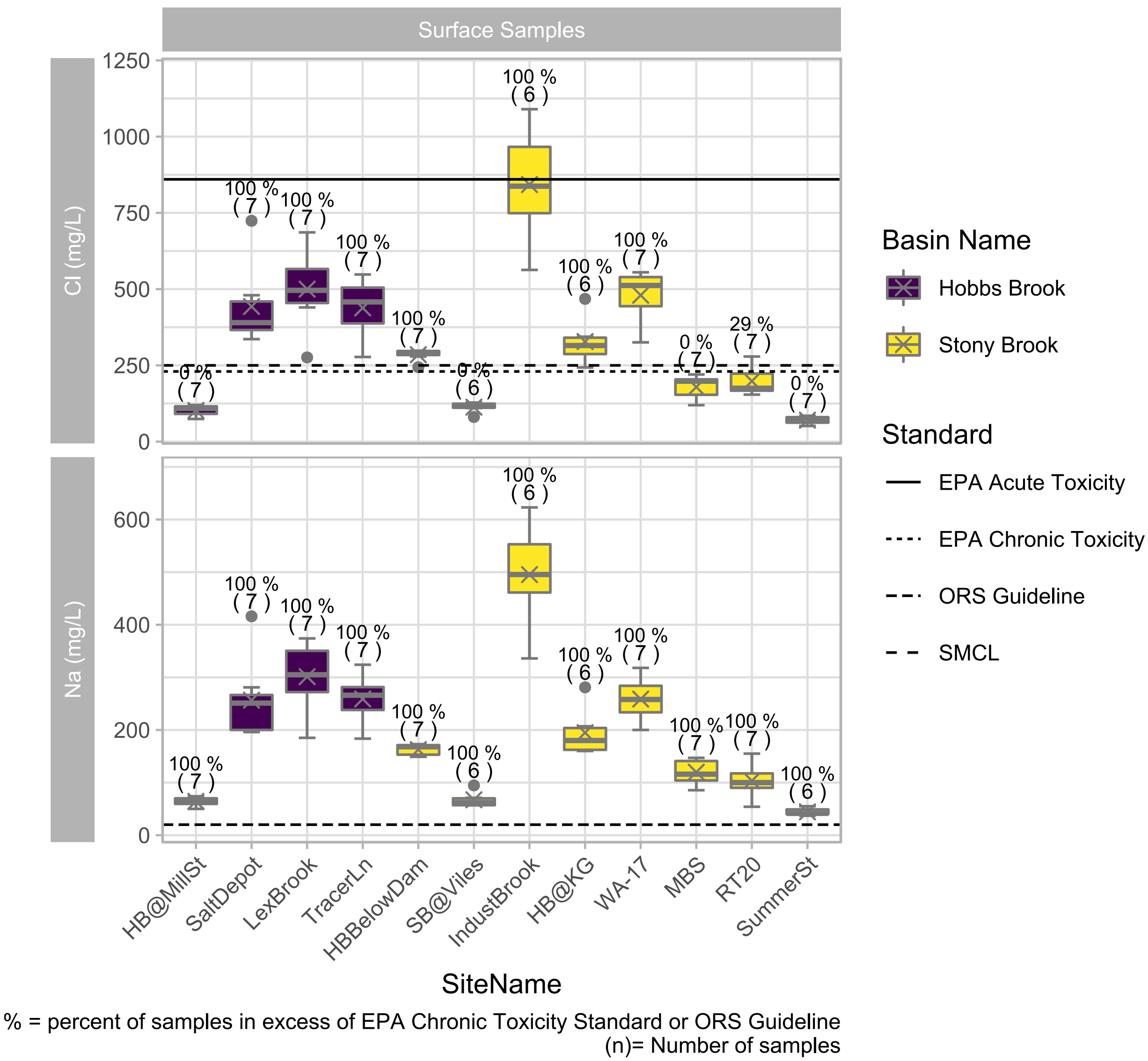


Figure 55: Tributary base-flow sodium and chloride, 2018

Table 30: Tributary base-flow sodium concentrations, 2018

Site Name	n	n>20 mg/L	%	Minimum	Maximum	Median	Mean
HB @ Mill St	7	7	100	**50**	**74**	**67**	**64**
Salt Depot	7	7	100	**196**	**416**	**251**	**257**
Lex Brook	7	7	100	**185**	**374**	**305**	**301**
Tracer Ln	7	7	100	**184**	**324**	**266**	**259**
HB Below Dam	7	7	100	**149**	**173**	**168**	**163**
SB @ Viles	5	6	100	**57**	**95**	**62**	**67**
Indust Brook	6	6	100	**336**	**623**	**496**	**495**
HB @ KG	6	6	100	**160**	**281**	**180**	**195**
WA-17	7	7	100	**200**	**318**	**258**	**259**
MBS	7	7	100	**86**	**147**	**116**	**120**
RT20	7	7	100	**54**	**155**	**100**	**103**
Summer St	6	6	100	**37**	**55**	**42**	**44**
n=number of samples, %= percent of samples in excess of the 20 mg/L ORS Guideline bolded values exceed the 20 mg/L ORS Guideline							

Table 31: Tributary base-flow chloride concentrations, 2018

		EPA acute toxicity		SMCL					
Site Name	**n**	**n>230 mg/L**	**%**	**n> 250 mg/L**	**%**	**Minimum**	**Maximum**	**Median**	**Mean**
HB @ Mill St	7	0	0	0	0	74	120	109	102
Salt Depot	7	7	100	7	100	**336**	**724**	**390**	**443**
Lex Brook	7	7	100	7	100	**276**	**686**	**496**	**500**
Tracer Ln	7	7	100	7	100	**278**	**548**	**458**	**438**
HB Below Dam	7	7	100	6	86	**244**	**298**	**291**	**285**
SB @ Viles	6	0	0	0	0	81	128	117	113
Indust Brook	6	6	100	6	100	**563**	**1,090**	**838**	**843**
HB @ KG	6	6	100	5	83	**243**	**468**	**315**	**328**
WA-17	7	7	100	7	100	**326**	**555**	**512**	**480**
MBS	7	0	0	0	0	120	220	198	179
RT20	7	2	29	2	29	154	**279**	175	198
Summer St	7	0	0	0	0	51	85	72	70
n = number of samples, % = percent of samples in excess of criterion or standard bolded values exceed the EPA chronic toxicity standard, underlined values exceed the SMCL									

The median chloride concentrations at HB Below Dam (291 mg/L) and HB @ KG (315 mg/L), downstream of the Hobbs Brook Reservoir, were on par with the median concentrations at HB @ Intake (286 mg/L) and HB @ DH (289 mg/L) (Table 23 and Table 31; Figure 26 and Figure 55). While all 2018 samples exceeded the EPA chronic toxicity standard and all but one sample exceeded the 250 mg/L SMCL at HB Below Dam and at HB @ KG, concentrations were much lower than at Salt Depot, Lex Brook, and Tracer Ln, where median levels ranged from 390 mg/L to 496 mg/L. The dilution of salt concentrations in Hobbs Brook Reservoir and the downstream monitoring station is partially due to HB @ Mill St, which had the lowest percentage of impervious cover in the watershed (8.3 percent) and the fewest miles of roads per square mile of catchment area[11] (6.4 mi/mi^2) (Table 3). HB @ Mill St also had the largest drainage area of the three Hobbs Brook tributary catchments at 2.15 mi^2 (Table 3).

Similarly, 2018 median concentrations in the Stony Brook Reservoir at SB @ DH and SB @ Intake (204 mg/L and 188 mg/L, respectively) were much lower than at Indust Brook and WA-17, which had two of the three highest chloride concentrations in the Cambridge watershed along with the highest percentages of impervious cover (Table 3, Table 23, and Table 31). This is because Indust Brook and WA-17 were among the smaller catchment areas in the Stony Brook subwatershed (Table 3). Larger catchment areas such as SB @ Viles, Summer St, and MBS had lower percentages of impervious cover and roadway miles relative to catchment area, which corresponded with lower median sodium and chloride concentrations (Table 3, Table 23, Table 30, and Table 31).

Summer St had the overall lowest median chloride concentration (72 mg/L) in the Cambridge watershed (Figure 55 and Table 31). Along with Summer St, median chloride concentrations at HB @ Mill St, SB @ Viles, RT 20, and MBS were below the 230 mg/L EPA chronic toxicity standard and the 250 mg/L SMCL in 2018. These catchments were among the least heavily developed areas in the watershed (Figure 3; Table 3 and Table 2). This meant less potential exposure to road salts than more heavily developed catchments with more miles of roadways and impervious cover. Except for RT 20, these sites are upstream of Hobbs Brook Reservoir, so they did not receive an influx of sodium and chloride when waters were released from the reservoir.

The trends in median sodium and chloride concentrations in the tributaries largely mirrored the median concentrations in the reservoirs, trending upwards after 2011 and leveling off in the 2015 to 2017 timeframe (Figure 56). Interestingly, Lex Brook appeared to overall trend downward, despite a temporary increase in concentration from 2012- 2015, perhaps suggesting reduced salt contributions from better managed deicing activities on I-95 and the Town of Lexington. Relative historical concentrations of sodium and chloride were largely consistent, with Salt Depot, Lex Brook, Tracer Ln, Indust Brook, and WA-17 having the highest median concentrations, and HB Below Dam and HB @ KG median exceeding the chloride EPA toxicity standard in beginning in 2014 and the 250 mg/L SMCL in 2015. Historic concentrations were also consistent with 2018 results in that HB @ Mill St, Summer St, Viles St, MBS, and RT 20 had the lowest salt concentrations.

[11] SB @ Viles had the same number of road miles per square mile of catchment, at 6.4 mi/mi^2

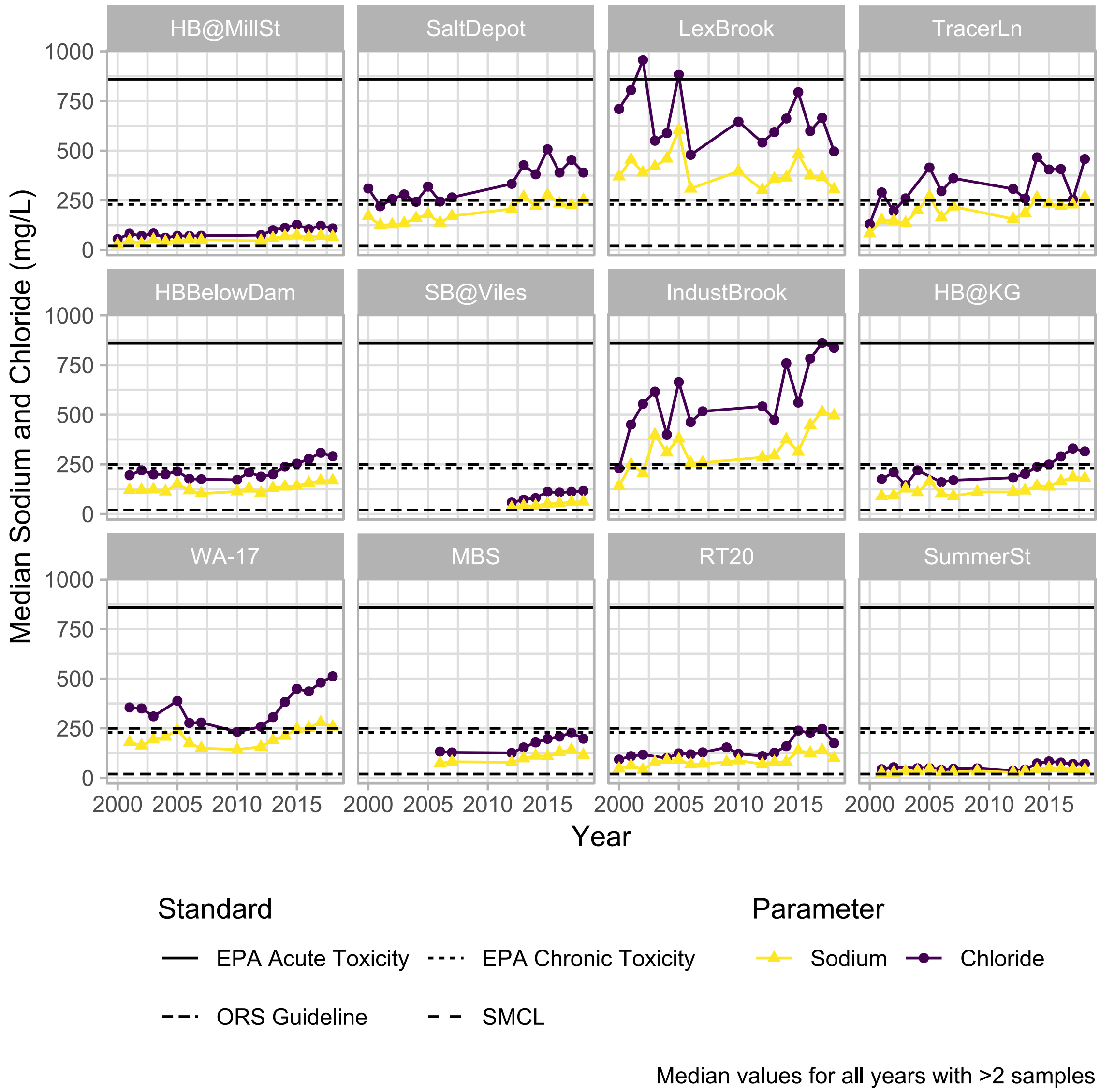


Figure 56: Median tributary sodium and chloride concentrations, 2000 – 2018

10 TRIBUTARY WET WEATHER WATER QUALITY

Stormwater runoff can have a big impact on water quality in developed watersheds. Impervious surfaces such as parking lots and roadways store metals, oils, and sediments from cars and other sources such as aerial deposition. During storms, these contaminants are rapidly shunted into streams via overland flow or piped drainage networks. The stormflow generated from these surfaces often occur at velocities high enough to erode banks.

In undeveloped watersheds, trees, uncompacted soils, and vegetation capture much of the stormwater runoff and disperse it gradually into streams or as recharge for groundwater. The amount of water flowing into streams under these conditions is not enough to exacerbate erosion and is generally of good quality.

The Cambridge watershed is highly developed in some areas. Pollution associated with sediment and particulates can be expected to increase during stormflow. Conversely, pollutants that are usually present in high levels in groundwater, like sodium and chloride, can become diluted during heavy rain events.

USGS maintains continuous monitoring stations outfitted to automatically sample storm events. In the Cambridge watershed, these are located at Lex Brook, Tracer Lane, WA-17 and Summer St. The USGS stormwater automated samples are taken throughout the entire storm, mixed together, and then analyzed for a variety of chemical and nutrient parameters. Between January and December 2018, the USGS sampled between five and six storm events at each of the four sites (Table 8). USGS also collected three water quality grab samples during base-flow conditions at each site.

USGS water quality data are available online by station ID number from the USGS National Water Information System web interface. All samples with a start and end date were categorized as wet weather samples in this report; all USGS samples collected under dry conditions per the USGS weather parameter (parameter code 41) and collected using a grab sample or open-mouth bottle sample method (per USGS parameter code 84164) were categorized as base-flow samples. All other USGS samples were excluded from the 2018 analyses but were included in a comparison of USGS 2018 water quality data to the USGS 1997 – 1998 baseline assessment.

10.1 TRIBUTARY 2018 STORMFLOW WATER QUALITY AND COMPARISON TO BASE-FLOW

Median 2018 sodium and chloride concentrations in all four catchments decreased during storm events due to dilution from runoff (Figure 57 and Figure 58). The difference in concentration between base-flow and stormflow samples was more pronounced in watershed catchments with high percentages of impervious cover and roadway miles relative to catchment area (Lexington Brook, Tracer Lane, WA-17) (Table 3; Figure 57 and Figure 58). USGS and CWD dry weather base-flow samples were generally well aligned.

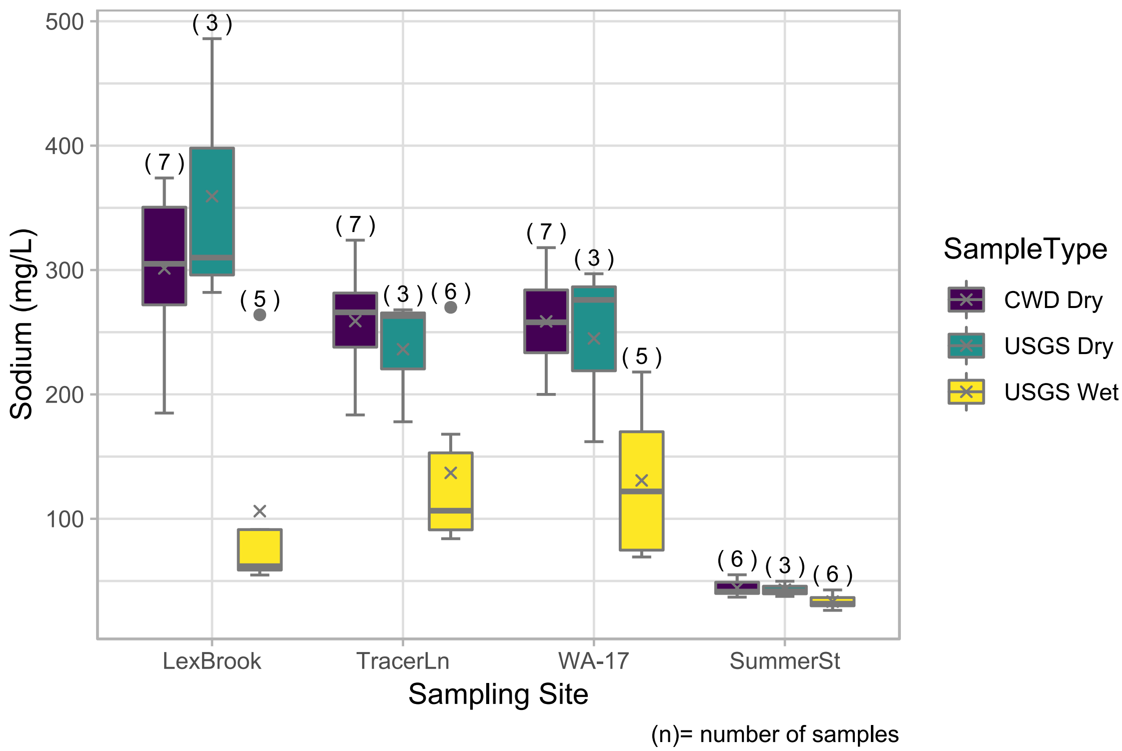


Figure 57: Tributary base-flow and stormflow sodium concentrations, 2018

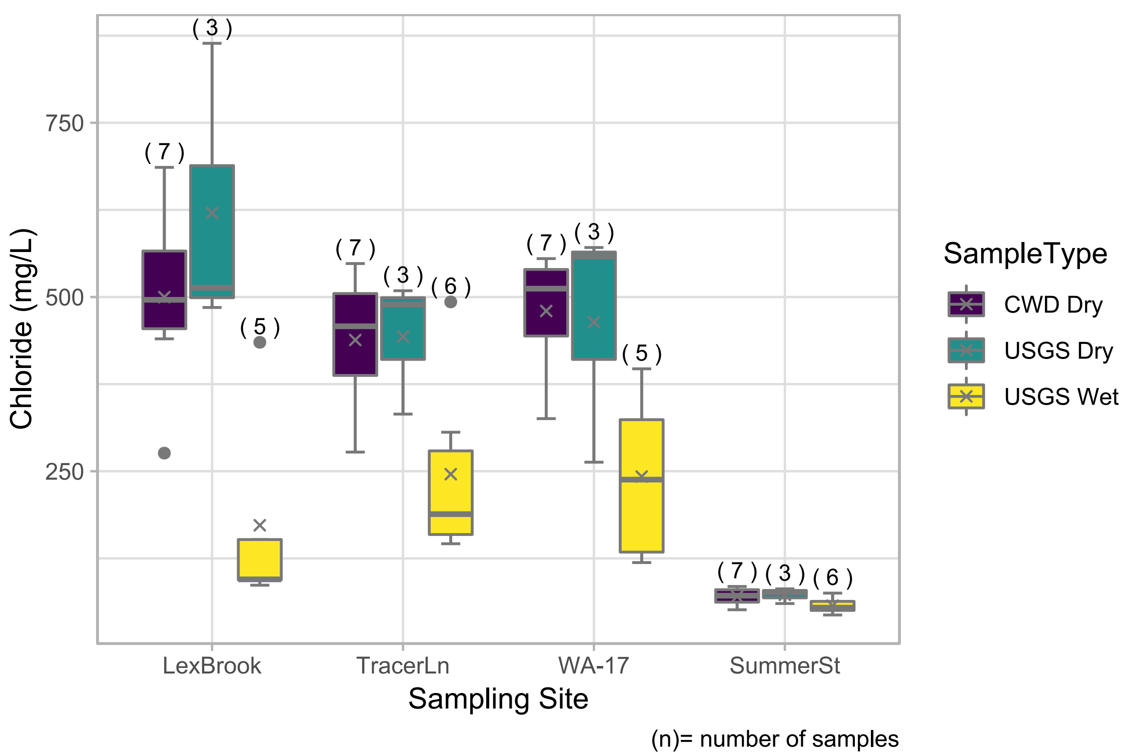


Figure 58: Tributary base-flow and stormflow chloride concentrations, 2018

Phosphorus tends to stay in the particulate phase and is thus introduced to the water supply most commonly in runoff. Sediment from vehicle tracking and erosion from construction or development activities are also potential sources of phosphorus. As of June 5, 2016, new regulations from the Massachusetts Department of Agricultural Resources prohibit the application of phosphorus containing fertilizers on lawns and turf fields unless soil tests indicate a phosphorus deficiency. More years of data are needed to determine whether the new regulations have had an impact on TP concentrations in the Cambridge watershed.

Total phosphorous concentrations were higher in stormflow samples than in baseflow samples at each site sampled in 2018 (Figure 59). Tracer Lane, which routinely receives stormwater discharges from the highway, had the highest TP concentration of the season during a storm on July 6 – 7th. This was 12 times higher than the maximum baseflow concentration of 2018. This is consistent with 2017 results (CWD, 2019b).

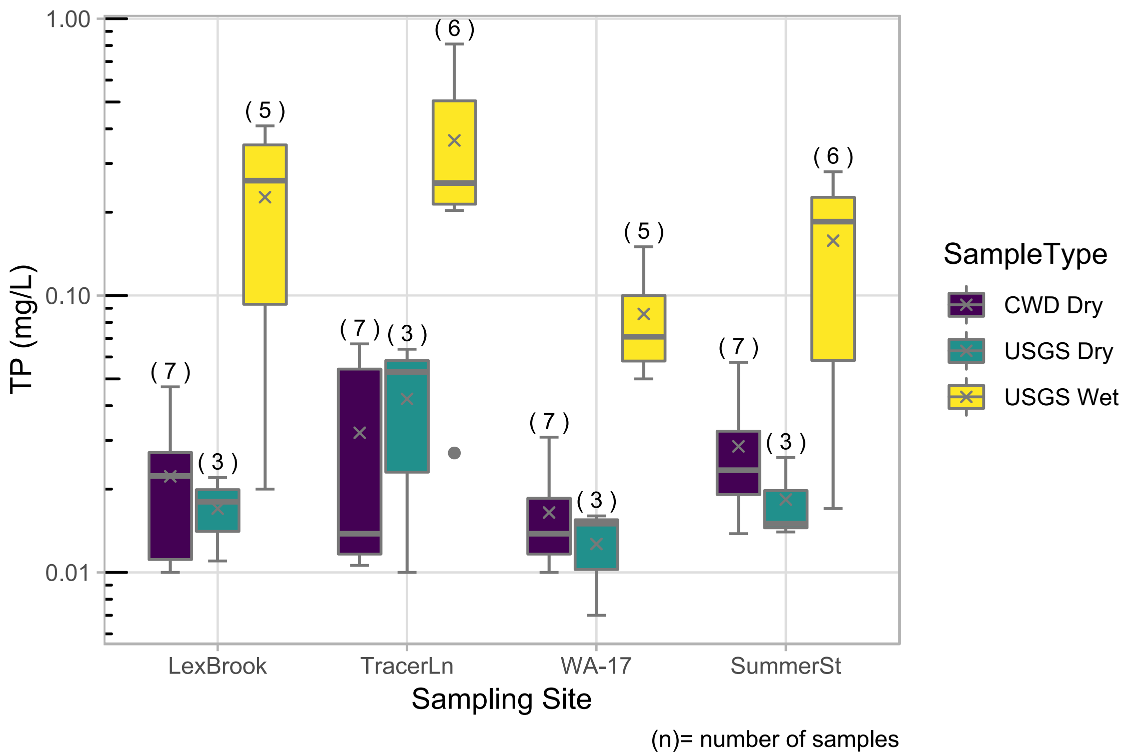


Figure 59: Lex Brook, Summer St, Tracer Ln, WA-17 base-flow and stormflow total phosphorous (TP) concentrations, 2018

In 2017, Lexington Brook showed a more muted response in TP concentration to stormflow, which seemed to suggest improvements in stormwater treatment devices along I-95 (CWD, 2019b). In 2018, however, the response was more pronounced again, which suggests a need for increased maintenance or additional stormwater treatment devices in the Lexington Brook catchment (Figure 59).

10.2 Comparison of 2018 USGS Water Quality Results to Baseline

From October 1997 – November 1998, stream-monitoring stations were sampled by the USGS in order to establish a baseline of water quality and develop guidelines for the current CWD water quality program (Waldron and Bent, 2000). Stream monitoring stations were sampled every 4 – 6 weeks for chemical analysis. Samples were collected by combining volumes of water proportional to the amount of discharge at 10-12 equally spaced points along the cross section of the stream. The USGS also conducted event sampling 8 times during different precipitation, snowmelt, and salt-application events. Sites were generally sampled 3 or 4 times over the course of the event. The combination of these data gives a broad sense of a baseline of water quality in different conditions.

USGS samples in 2018 were collected at the stream monitoring stations using auto-samplers to create flow proportional composite samples during storm events and to collect discrete samples triggered by incremental changes in specific conductance. The USGS also sampled by hand during dry weather. Despite the differences in sampling methodologies, an approximate comparison can be made between the of the the USGS 1997 – 1999 baseline study and the USGS 2018 results.

Sodium and chloride concentrations at WA-17 and Summer St seem to have increased between the baseline samples of the 1990s and 2018 (Figure 60 and Figure 61). Due to the application of road salt on highways directly adjacent to WA-17, the redevelopment of the old Polaroid campus at 1265 Main Street, and the likely lingering effects of the below normal precipitation from 2012 – 2017, this is not unexpected. This matches the trend in median sodium and chloride base-flow concentrations measured by CWD since 2000, which showed increasing salt concentrations corresponding with a pattern of below normal precipitation from 2012-2017 (Figure 56).

Tracer Lane median concentrations of sodium and chloride are actually very close to what was measured in the 1990s (Figure 60 and Figure 61). There has been little change at all, except for fewer high concentration outliers measured in 2018 when compared to the 1990’s baseline study.

Lex Brook experienced an apparent decrease in concentrations of sodium and chloride since the 1997-1998 baseline study (Figure 60 and Figure 61). This result is consistent with the observed trend in decreasing median sodium and chloride base-flow concentrations measured by CWD since 2000 (Figure 56). This improvement in water quality suggests a reduction in salt contamination from roadway deicing, perhaps from improved highway and town (Lexington) deicing practices. If this is the case, the reduction in salt concentrations is encouraging, and shows that with the right best management practices, it is possible for water quality to improve over time.

Phosphorous has markedly increased at all 4 sites since the baseline study (Figure 62). Sources of phosphorous could include fertilizers, the natural weathering of rocks and soils, and septic tank leaks and failures (Smith, 2013). In the developed Cambridge watershed, it is possible that sediment from vehicles or erosion from various construction projects could be contributing to the increase of phosphorous over time in the watershed. It is also possible that today’s better wet weather sampling techniques more accurately characterize event TP concentrations. As stated previously, the baseline study did not use autosamplers, rather discrete grab samples taken only three to four times during the course of the event.

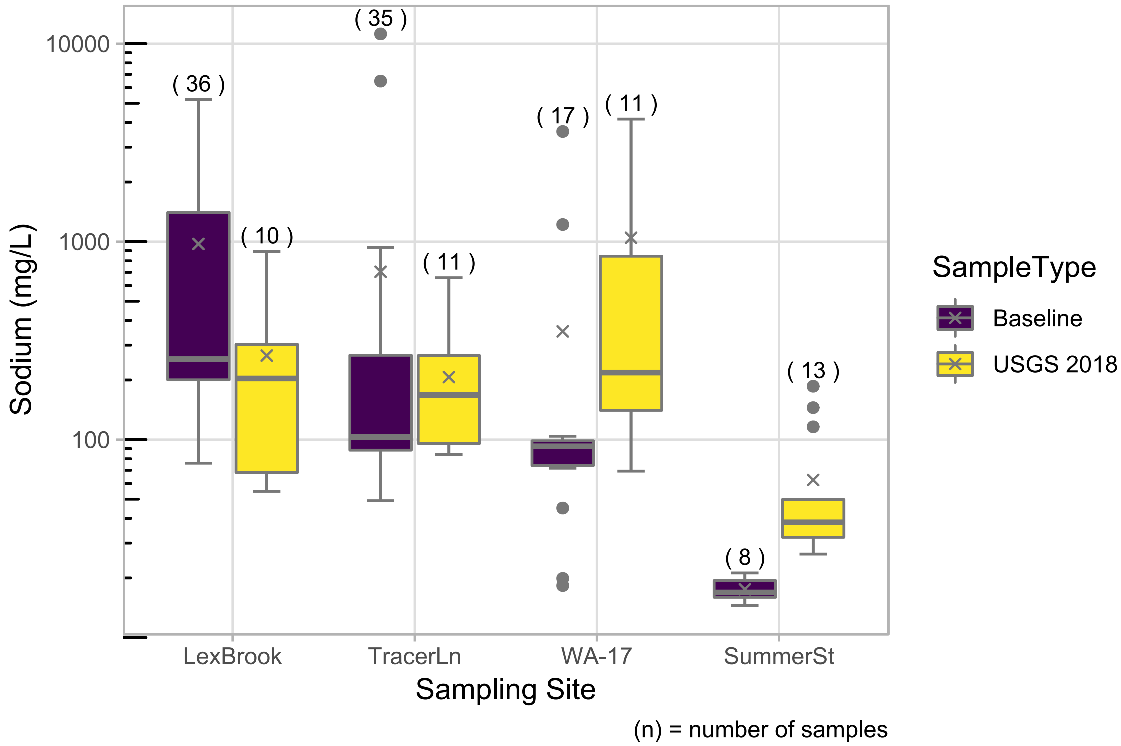


Figure 60: Lex Brook, Summer St, Tracer Ln, and WA-17 USGS sodium water quality results, 1997-1998 baseline study and 2018

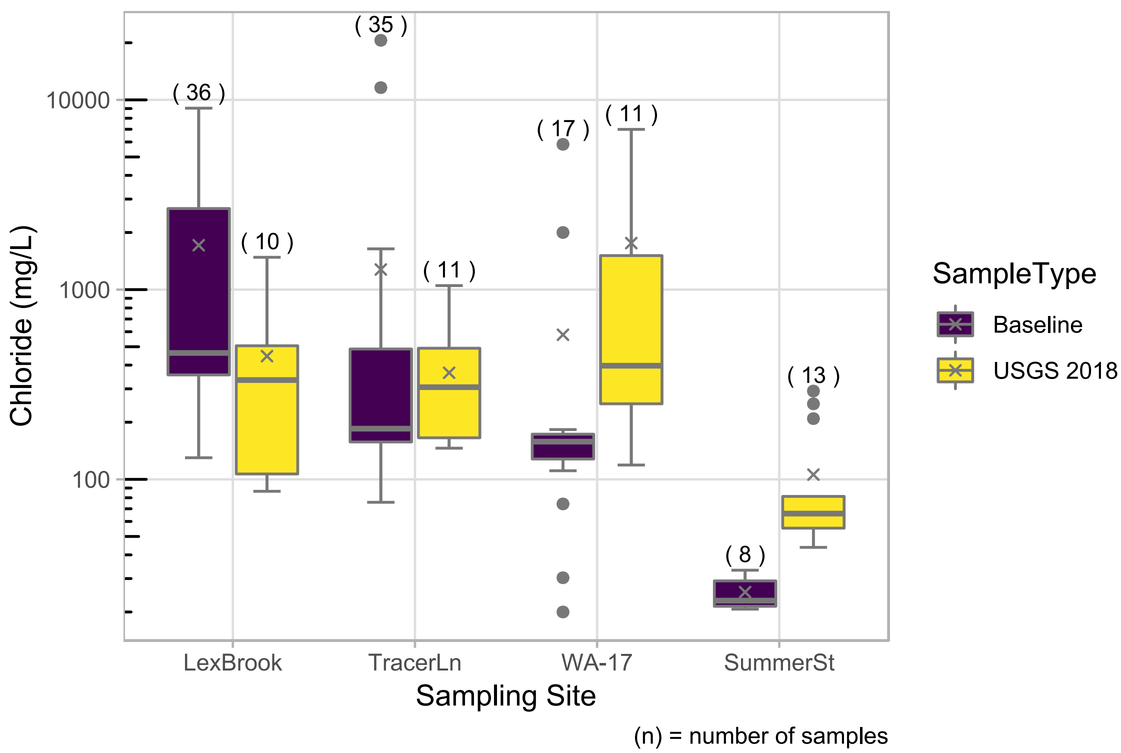


Figure 61: Lex Brook, Summer St, Tracer Ln, and WA-17 USGS chloride water quality results, 1997-1998 baseline study and 2018

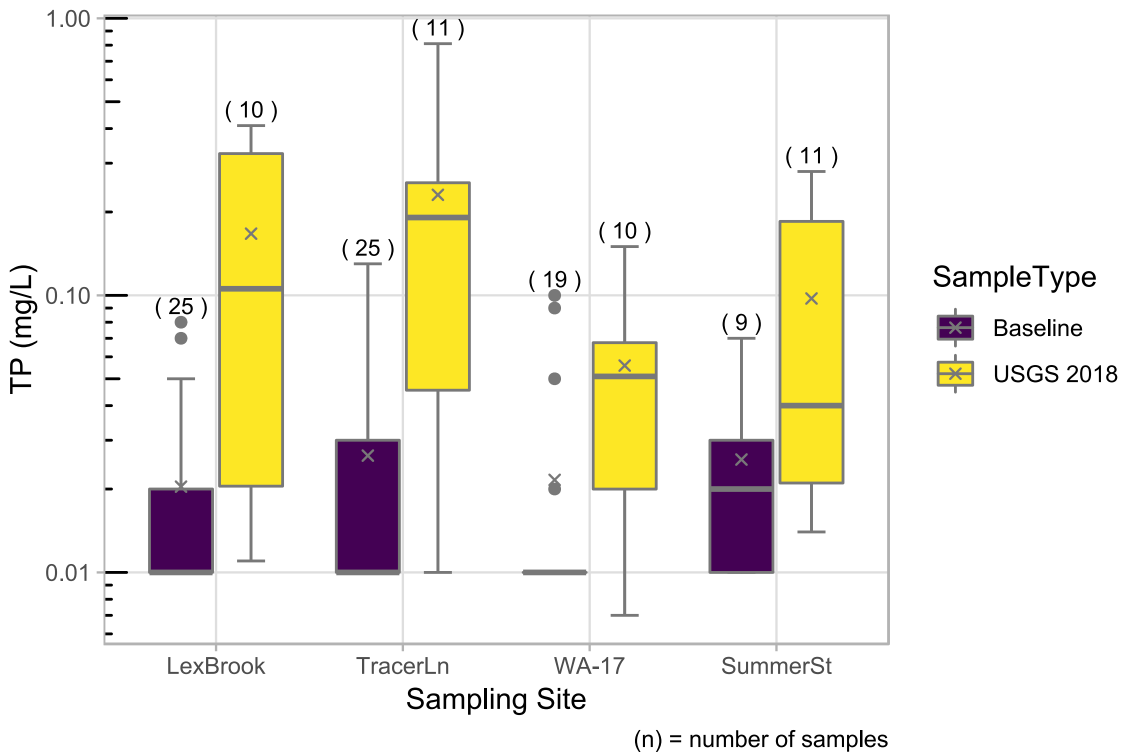


Figure 62: Lex Brook, Summer St, Tracer Ln, and WA-17 USGS total phosphorus (TP) water quality results, 1997-1998 baseline study and 2018

11 LOADS AND YIELDS

The impact of a tributary on reservoir water quality depends not only on pollutant concentration, but also on the volume of water flowing through the tributary catchment over time. For example, a small (low flow) tributary with a high salt concentration may transport less total sodium into a reservoir during a given timeframe than a large (high flow) tributary with a lower concentration of sodium. The tributary annual load is defined as the total quantity of a pollutant transported by a stream or river in a year. Understanding the contribution of each tributary to reservoir pollutant loads can help prioritize and target management activities within the watershed. The tributary yield is defined as the load divided by the tributary catchment area. Standardizing by area to derive the yield allows for normalized comparisons of tributary loads between sites.

Annual base-flow loads and yields of sodium, chloride, TN, and TP were calculated at each monitoring station. At sites where stormwater water quality data were available (Lex Brook, Tracer Ln, WA-17, and Summer St), stormwater loads and yields were also computed and reported. See Appendix C for the methods used to calculate loads and yields at each tributary site.

11.1 BASE-FLOW LOADS AND YIELDS

11.1.1 Sodium and Chloride

The three sites with the highest sodium and chloride base-flow loads were RT 20 (sodium = 3,928 tons, chloride= 7,531 tons), HB @ KG (sodium = 2,344 tons, chloride = 3,945 tons), and HB Below Dam (sodium = 1,546 tons, chloride = 2,709 tons) (Figure 63 and Figure 64). HB @ KG is downstream of HB Below Dam, so it was expected that HB @ KG would produce a higher load of salt than HB Below Dam. Similarly, RT 20 is down stream of all tributary catchment sites except for Summer St and had the largest drainage area in the watershed, so it was also expected to produce the highest loads.

The large drainage areas of RT 20, HB @ KG, and HB Below Dam (22.0 mi^2, 8.48 mi^2, and 6.95 mi^2, respectively) primarily explain the large loads relative to the other sites. However, the SB @ Viles watershed (10.4 mi^2) was larger than both HB @ KG and HB Below Dam, yet the SB @ Viles sodium and chloride loads were lower (Figure 63 and Figure 64). In this case, the much lower sodium and chloride concentrations at SB @ Viles St resulted in a lower load, despite the larger drainage area. This was reflected in the sodium and chloride yields – SB @ Viles produced the least amount of sodium and chloride of any tributary site in the watershed on a per area basis (111 tons/mi^2 of sodium and 187 tons/ mi^2 of chloride) except for Summer St and HB @ Mill St (Figure 63 and Figure 64).

When comparing yields, RT 20 produced only the eighth highest amounts of sodium and chloride on a square mile basis despite generating greatest overall load of sodium and chloride (Figure 63 and Figure 64). The sites with the highest yields of sodium and chloride were the same sites with the highest median sodium and chloride concentrations (Indust Brook, Tracer Ln, Lex Brook, Salt Depot, and WA-17) (Figure 55, Figure 63, and Figure 64). These sites also had the greatest percentages of impervious cover and roadway miles per square mile of catchment, except for Salt Depot which had elevated salt concentrations due to a historic groundwater salt plume (Table 3; Geotechnical Engineers Inc., 1985).

Indust Brook, the site with the highest median sodium and chloride concentrations and highest yields (650 tons/mi^2 and 1,106 tons/mi^2, respectively) has one of the smallest drainage areas in the watershed at only 0.33 mi^2 (Figure 55, Figure 63, and Figure 64). As such, the loads of sodium and chloride generated by Indust Brook were low compared to other sites.

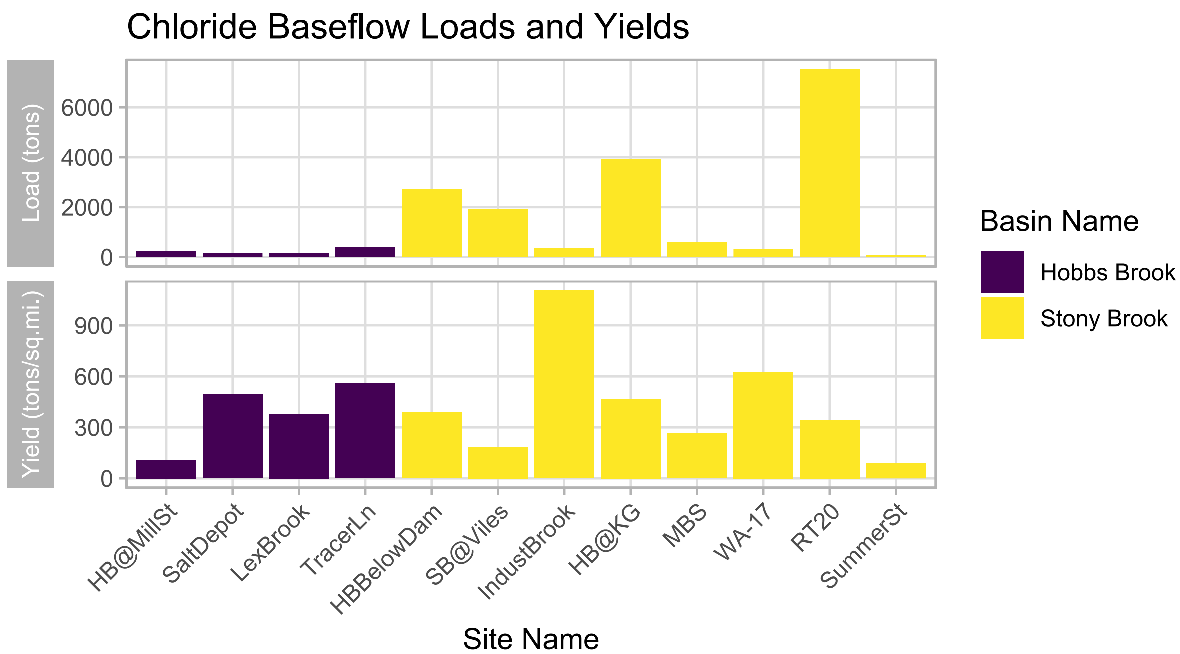


Figure 63: Tributary base-flow chloride loads and yields, 2018

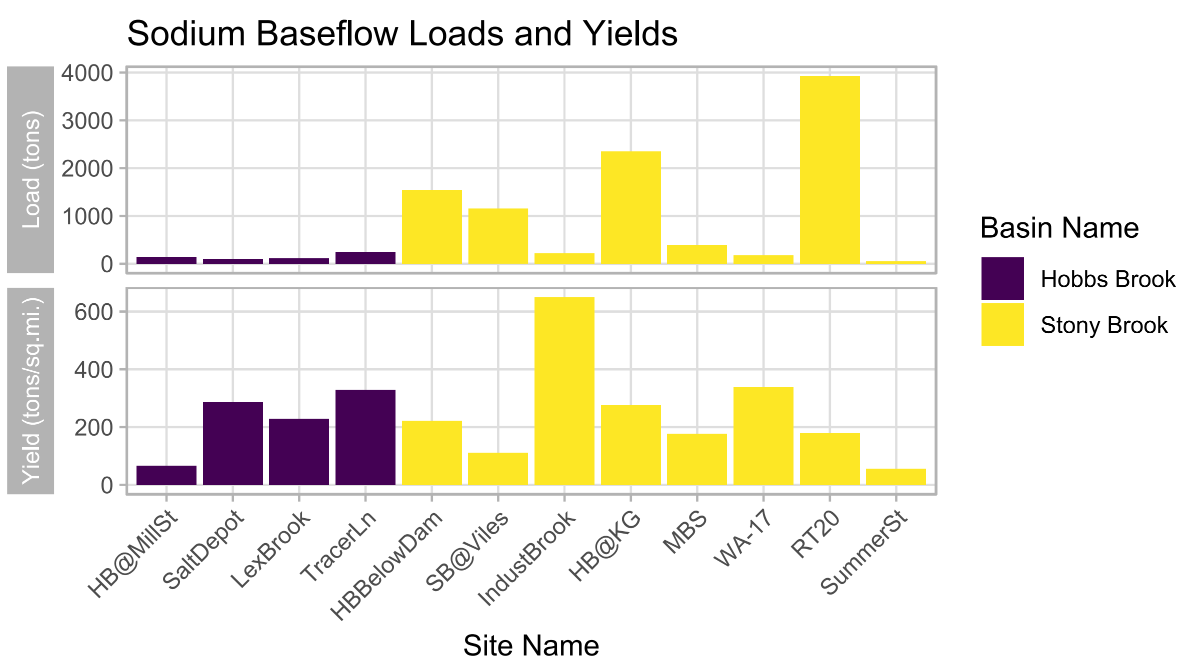


Figure 64: Tributary base-flow sodium loads and yields, 2018

11.1.2 Nutrients

Loads of TN decreased with tributary catchment size except for Indust Brook (Figure 65). Indust Brook has the smallest catchment area (0.33 mi^2) but the third smallest TN load (0.69 tons per mi^2). On a square mile basis, Stony Brook basin tributaries generally passed more TN than the Hobbs Brook basin tributaries. HB Below Dam and HB @ KG, the two sites most heavily influenced by releases of water from the Hobbs Brook Reservoir, were the only Stony Brook basin sites with lower TN yields than Hobbs Brook basin tributaries (although both sites had higher yields than Salt Depot Brook). The highest TN yields were produced by Summer St (2.7 tons/mi^2), WA-17 (2.5 tons/mi^2), SB @ Viles (2.4 tons/mi^2), and Indust Brook (2.1 tons/mi^2), the same sites with the highest median TN concentrations in 2018 (Figure 51 and Figure 65).

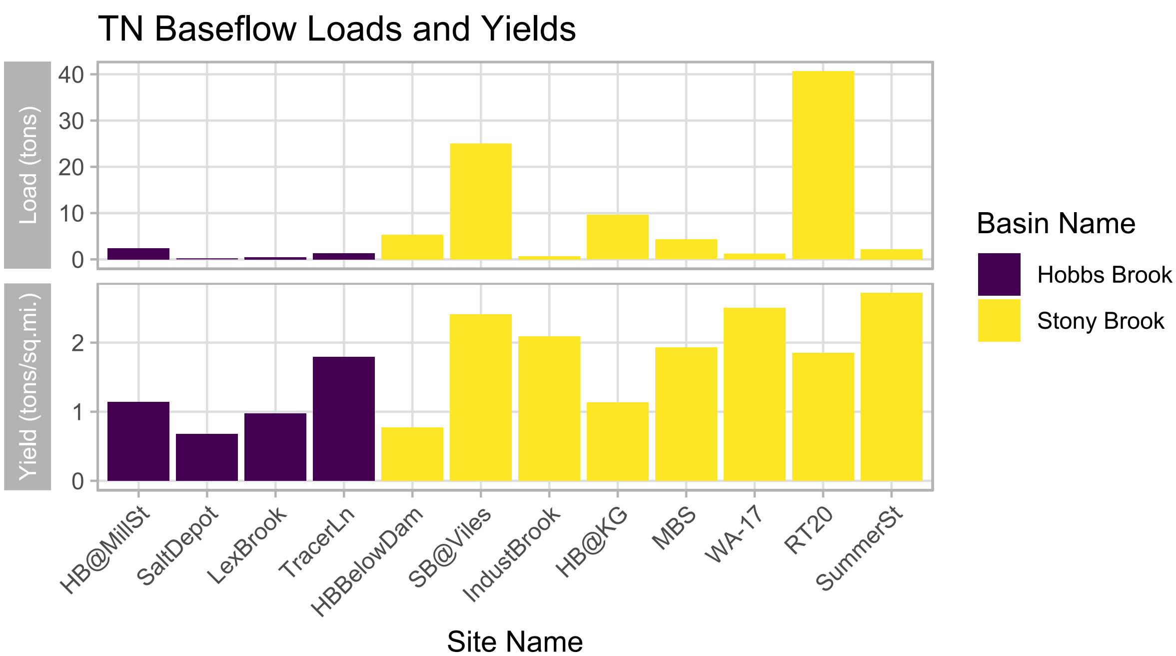


Figure 65: Tributary base-flow total nitrogen loads and yields, 2018

TP loads were highest in the four largest tributary catchments, with RT 20 (which receives loads from all sites except for Summer St) generating the largest load in 2018 (0.80 tons) (Figure 66). On a square mile basis, the two highest yields were from Tracer Ln and Indust Brook followed by RT 20, Summer St, and Mill St (Figure 66).

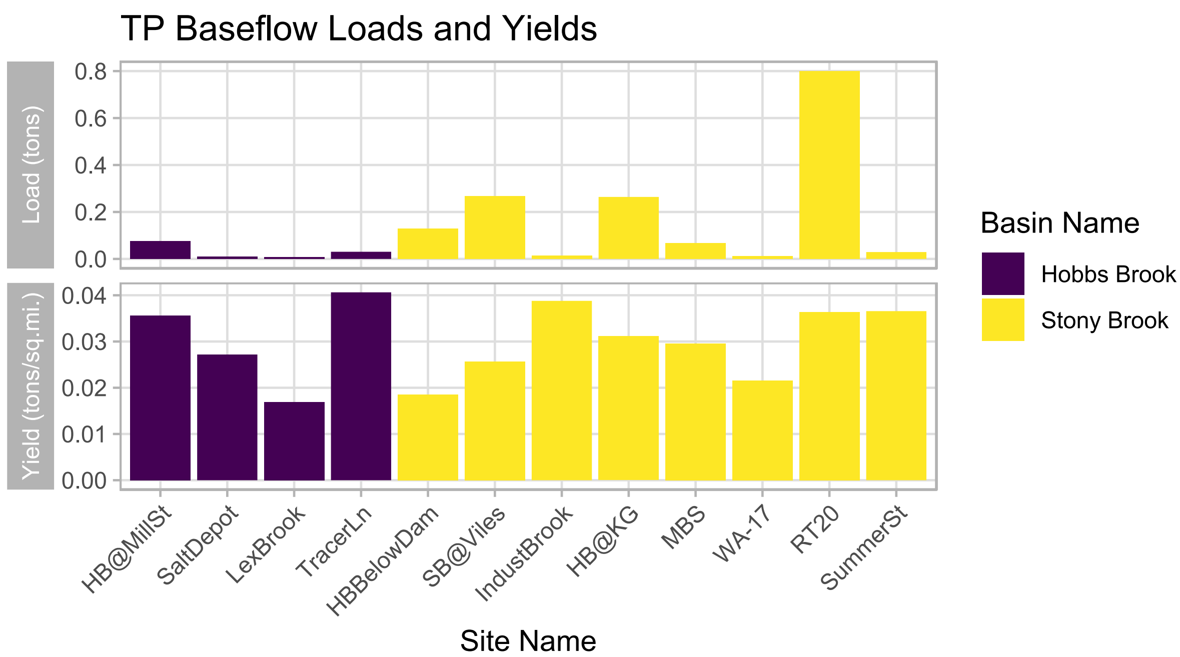


Figure 66: Tributary base-flow total phosphorus loads and yields, 2018

11.2 Comparison of Base-flow and Stormflow Loads and Yields

Using mean concentrations of sodium, chloride, and TP from stormwater samples collected by the USGS during stormflow and CWD during base-flow, stormflow and base-flow loads and yields in 2018 were analyzed for Lex Brook, Tracer Ln, WA-17, and Summer St. The USGS did not collect stormwater samples for nitrogen compounds in 2018.

After adding stormflow to base-flow, total loads and yields for sodium and chloride were still higher at Lex Brook, Tracer Ln, and WA-17 than at Summer St (Figure 67). This was unsurprising since the percentage of impervious area and roadway to catchment area ratio was much lower at Summer St (12 percent and 8.0 mi/mi^2) than and in the other three catchments where the percent impervious ranged from 30.7 percent to 37.1 and the roadway miles ratio ranged from 17.1 mi/mi^2 to 24.8 mi/mi^2 (Table 3). Base-flow contributed the majority of the sodium and chloride load at each site, ranging from 62 percent to 72 percent (Table 32), suggesting that salt-contaminated groundwater was a significant component of salt loads. Presumably, sodium and chloride enter the water table by dissolving and infiltrating into the ground after being applied as deicing chemicals during winter storms.

Table 32: Base-flow and stormflow load percentages, 2018

Site Name	Sodium load (%)		Chloride load (%)		TP load (%)	
	Base-flow	Stormflow	Base-flow	Stormflow	Base-flow	Stormflow
Lex Brook	67%	33%	67%	33%	6%	94%
Tracer Ln	63%	37%	62%	38%	7%	93%
WA-17	72%	28%	72%	28%	20%	80%
Summer St	70%	30%	69%	31%	24%	76%

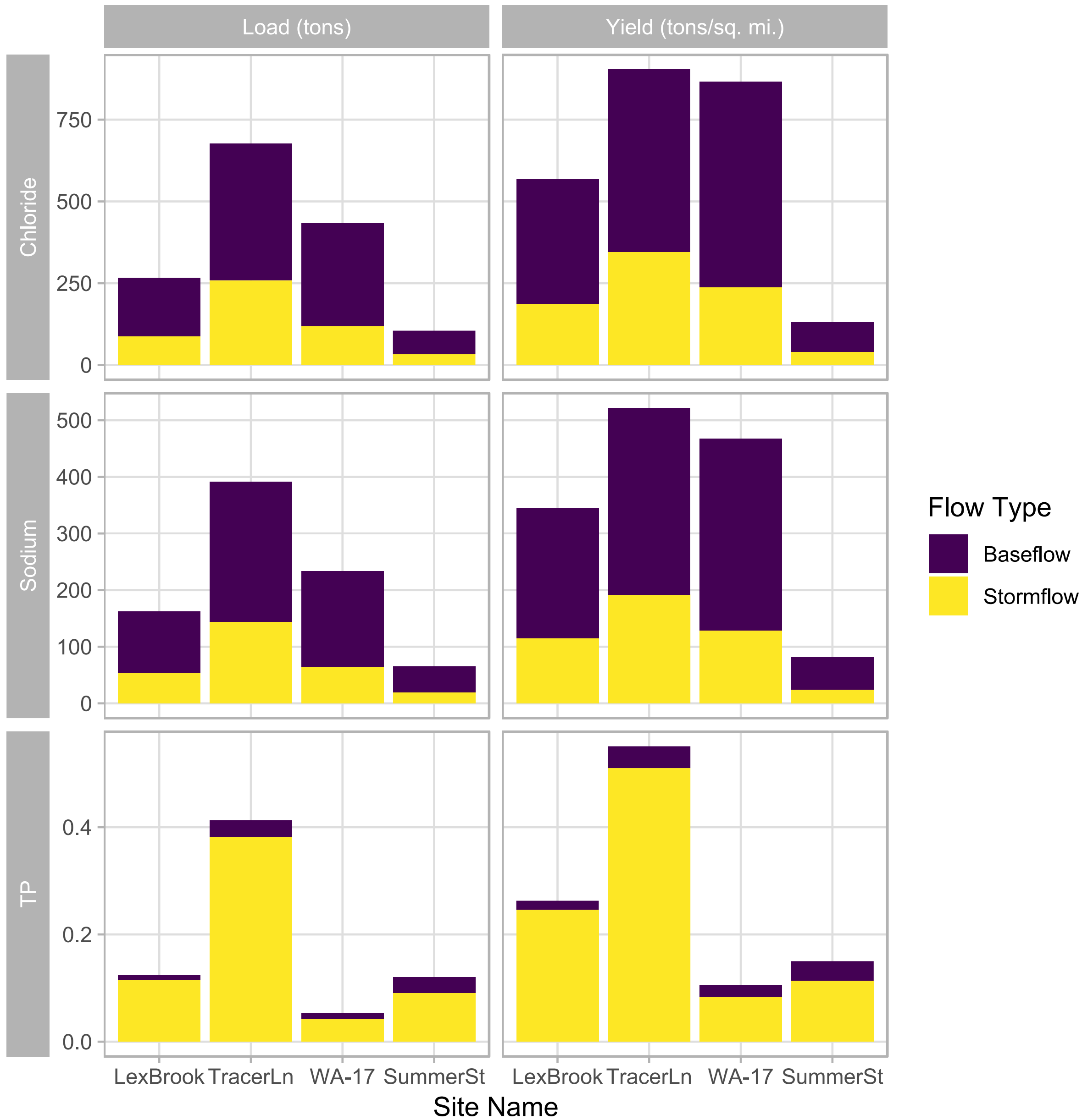


Figure 67: Base-flow and stormflow load and yield comparisons at Lex Brook, Tracer Ln, WA-17, and Summer St, 2018

Tracer Ln had the highest annual total TP load and yield of the four sites (0.41 tons and 0.55 tons/mi^2) whereas WA-17 had the lowest (0.05 tons and 0.11 tons/mi^2). The TP load and yield at WA-17 were lower than at Summer St, despite having a higher percentage of impervious cover, and lower than Tracer Ln and Lex Brook, despite having a comparable to higher level of impervious cover (Table 3). This suggests that while the stormwater treatment pond installed upstream of WA-17 in 2012 likely worsened base-flow water quality, it may have improved stormwater quality. However, Smith (2013) did not find a statistically significant difference when using the Mann Whitney test to compare TP stormwater samples collected between water years 2005-2007 and 2013-2015, before and after the stormwater basin installation, suggesting that the new stormwater treatment system at WA-17 had no impact on stormwater water quality.

Percentages of TP loads attributable stormflow were opposite that of sodium and chloride, with stormflow accounting for between 76 percent (Summer St) and 94 percent (Lex Brook) of the total TP load (Table 32). The high contribution of the TP load from stormflow at all sites demonstrates the importance of stormwater best management practices in addressing TP pollution.

12 Reservoir Retention Time

12.1 Retention Time Overview

Reservoir retention time is the amount of time necessary for a reservoir to refill if it were completely empty, or the amount of time that it would take to drain if inputs ceased. The retention time is also defined as the average amount of time a water molecule remains in a waterbody, or the flushing rate. Reservoir retention time assumes equal inflows and outflows to the reservoir and is calculated by dividing the total storage capacity by the total inflows to, or outflows from, the waterbody. Reservoirs with longer retention times (low flushing rate) may respond slower to degradation or improvement of inflow water quality; water in a reservoir with a shorter retention time (high flushing rate) will turn over more quickly. Therefore, changes in source water quality are likely to impact reservoir water quality faster when the retention time is shorter.

The retention times of the Hobbs Brook and Stony Brook Reservoirs were calculated using outflow data from USGS monitoring stations. CWD raw water intake data from Fresh Pond to the Walter J. Sullivan Treatment Plant was used to quantify outflows from Fresh Pond. Cambridge reservoirs are managed water bodies, so variations in the timing of water releases can result in an imbalance between reservoir inflows and outflows within a year. Despite annual variation in reservoir storage, the Cambridge reservoirs are in long-term equilibrium.

12.2 Reservoir Retention Times

The Hobbs Brook Reservoir had the longest retention time of the three reservoirs (Table 33, Table 34, and Table 36). The hydraulic retention time in 2018 was 15 months and was also 15 months for the ten-year average. The 2018 annual outflow from Hobbs Brook Reservoir, as measured at the HB Below Dam monitoring station (USGS station 01104430), was 2.278 billion gallons (Table 33).

Table 33: Hobbs Brook Reservoir retention time, 2009-2018

Year	Hobbs Outflow (MG)	Storage Capacity (MG)	Estimated Retention Time (months)
2009	3,613	2,898	10
2010	4,889	2,518	6
2011	2,653	2,518	11
2012	1,806	2,518	17
2013	1,431	2,518	21
2014	2,565	2,518	12
2015	2,858	2,898	12
2016	1,671	2,898	21
2017	1,685	2,898	21
2018	2,278	2,898	15

The retention time at the Hobbs Brook Reservoir was calculated using the total storage capacity of 2.518 billion gallons for 2010-2014 and 2.898 billion gallons for 2008-2009. The difference in storage capacity is due to the removal of spillway flash boards at the Hobbs Brook Dam in 2010. The flash boards were replaced in 2015[12] increasing the storage capacity back to 2.898 billion gallons.

Stony Brook Reservoir retention time was 15 days (about 0.5 months) in 2018, the shortest retention time of all three reservoirs in the Cambridge water supply system (Table 34). Inputs to the Stony Brook Reservoir are contributed primarily by its watershed during winter and spring and from the Hobbs Brook Reservoir during the summer and fall. From the Stony Brook Reservoir, water is diverted to Fresh Pond via an aqueduct, and excess water is released into the Charles River. Outflow to the Charles River was estimated from the USGS gaging station located downstream of the Stony Brook gatehouse.

Table 34: Stony Brook Reservoir retention time, 2009-2018

Year	Stony to Charles (MG)	Stony to Fresh Pond (MG)	Total Output from Stony (MG)	Storage Capacity (MG)	Estimated Retention Time (days)
2009	7,725	Data not available	Data not available	418	--
2010	10,514	Data not available	Data not available	418	--
2011	7,663	4,899	12,562	418	11
2012	2,177	5,256	7,433	418	22
2013	4,220	4,098	8,318	418	18
2014	5,473	4,317	9,790	418	15
2015	2,375	5,691	8,066	418	18
2016*	1,863	4,230	6,093	418	26
2017	3111	4976	8087	418	18
2018	6418	5319	11,737	418	15
*2016 Conduit flow data gaps 8/17, 8/23, 9/20-10/16 were estimated based on average conduit flows during similar time periods.					

The annual rain total for 2018 (58.36 inches) at the Hobbs Brook Reservoir USGS station was the highest of the last 10 years (Table 35). The 2018 precipitation total was more than 12 inches above the 45.71 inch National Oceanic and Atmospheric Administration (NOAA) 1981-2010 normal recorded at the Bedford Hanscom Field, MA weather station[13] and was the first year since 2014 with above normal precipitation[14]. This resulted in an increase in the amount of flow released to the Charles River compared to recent years, although 2009 - 2011 resulted in more flows released to the Charles despite overall lower precipitation totals (Table 35 and Figure 68).

[12] The flashboards were replaced between 2014 and 2015, although the exact timing of the replacement is unknown. These calculations assume the replacement did not occur until 2015.

[13] Climate normal data were accessed from the NOAA National Centers for Environmental Information website at https://www.ncdc.noaa.gov/cdo-web/datatools/normals.

[14] The 2014 precipitation total at the NOAA Bedford Hanscom Field, MA weather station was below normal as shown in Figure 31. The precipitation measured at USGS station 01104430 was above normal in 2014 (Table 35).

Table 35: Hobbs Brook Below Dam USGS station (01104430) total annual precipitation (inches)

Year	2009	2010	2011	2012	2013	2014	2015	2016*	2017**	2018**
Total Precipitation	47.69	54.67	57.04	43.8	40.17	48.31	33.33	36.67	42.87	58.36
*Data were from USGS meteorological station 422518071162501 due to missing precipitation data from USGS station 01104430 from 2/18-3/3 in 2015 and 2/4-2/8, 2/10, 2/14-2/16, and 4/4-4/5. **2017 and 2018 provisional data subject to revision.										

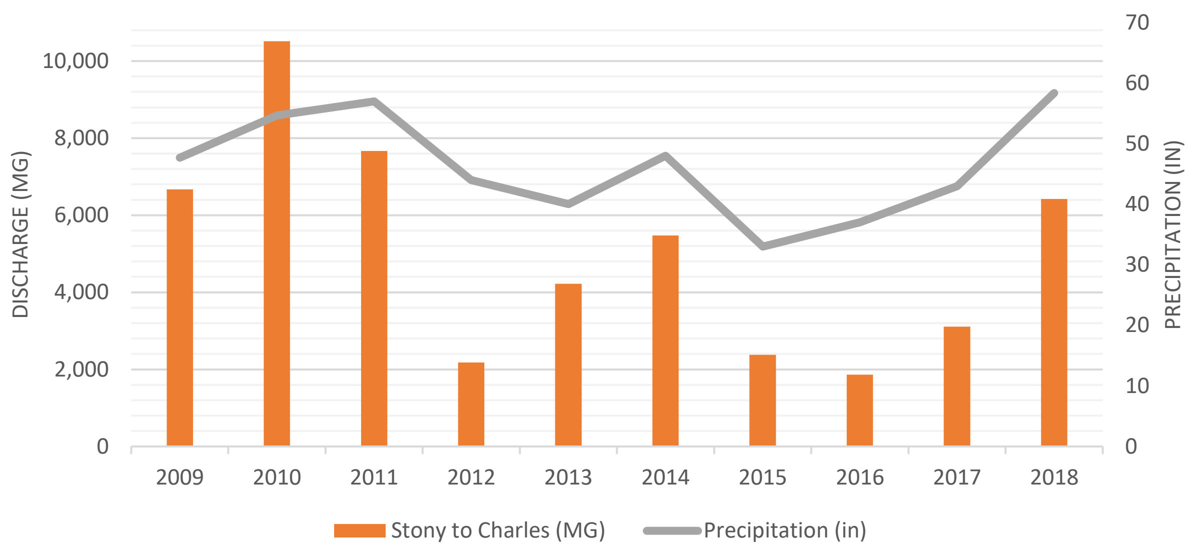


Figure 68: Total discharge from Stony Brook Reservoir to the Charles River and total precipitation, 2009-2018

Total output from Fresh Pond to the treatment plant (estimated from the total water produced by the plant) was 4.733 billion gallons in 2018 and Fresh Pond had a retention time of 3.8 months, slightly quicker than the 10 year average of 4.1 months (Table 36). Water supplied in 2018 almost entirely originated from the Cambridge watershed. However, Cambridge also purchased 9.28 million gallons of supplemental MWRA water during August of 2018.

Table 36: Fresh Pond Reservoir Retention Time, 2009-2018

Year	Fresh Pond to WTP (MG)	Storage Capacity (MG)	Estimated Retention Time (months)
2009	4,748	1,507	3.8
2010	4,850	1,507	3.7
2011	4,709	1,507	3.8
2012	4,749	1,507	3.8
2013	3,552	1,507	5.0
2014	3,764	1,507	4.8
2015	5,068	1,507	3.6
2016	3,855	1,507	4.7
2017	4,690*	1,507	3.8
2018	4,733	1,507	3.8
*Volume corrected from 2017 Source Water Quality Report (CWD, 2019b)			

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14 GLOSSARY

Algal bloom— The rapid proliferation of passively floating, simple plant life in and on a body of water.

Anoxic— The absence of oxygen; anaerobic. DO below 0.5 mg/L.

Benthic sediments— The surface layer and some sub-surface layers of sediment in contact with the bottom zone of a water body, such as a lake or ocean.

Discharge (hydraulics)— Rate of flow, especially fluid flow; a volume of liquid passing a point per unit of time, commonly expressed in cubic feet per second, million gallons per day, or liters per second.

Dissolved oxygen (DO) — Oxygen dissolved in water; one of the most important indicators of the condition of a water body. Dissolved oxygen is necessary for the life of fish and most other aquatic organisms.

Drainage basin— Land area drained by a river or stream; watershed.

Epilimnion— Warm, oxygen-rich, upper layer of water in a lake or other body of water, usually seasonal. *See also* Metalimnion, Hypolimnion

Eutrophic— Term applied to a body of water with a high degree of nutrient enrichment and high productivity.

Eutrophication— Process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

***Escherichia coli* (*E. coli*) bacteria**— Type of bacteria that is found in the human gastrointestinal tract. *E. coli* is commonly used as an indicator of fecal contamination in groundwater, as the result of an improper sewage connection or septic system failure.

Groundwater— In the broadest sense, all subsurface water, as distinct from surface water; as more commonly used, that part of the subsurface water in the saturated zone. *See also* Surface water.

Hypolimnion— Cold, oxygen-poor, deep layer of water in a lake or other water body. *See also* Epilimnion, Metalimnion.

Hypoxic — The deprivation of oxygen compared to how much is required by the system. DO below approximately 2 mg/L.

Load— Material that is moved or carried by streams, reported as the weight of the material transported during a specific time period, such as kilograms per day or tons per year.

Maximum contaminant level (MCL)— Maximum permissible level of a contaminant in water that is delivered to any user of a public water system, established by a regulatory agency such as the U.S. Environmental Protection Agency. *See also* Secondary maximum contaminant level.

Mean— The arithmetic average obtained by dividing the sum of a set of quantities by the number of quantities in the set.

Median— The middle or central value in a distribution of data ranked in order of magnitude. The median also is known as the 50th percentile.

Mesotrophic— Term applied to a body of water with intermediate nutrient content and intermediate productivity.

Metalimnion— Transition zone between the warm upper layer and the cold deep layer of a lake or other water body, characterized by rapidly decreasing temperature with increasing depth. *See also* Epilimnion, Hypolimnion.

Minimum reporting limit (MRL) — The lowest measured concentration of a constituent that can be reported reliably using a given analytical method.

Monitoring station— A site on a stream, canal, lake, or reservoir used to observe systematically the chemical quality and discharge or stage of water.

Nutrient— An element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Oligotrophic— Term applied to a body of water low in nutrients and in productivity.

pH— The logarithm of the reciprocal of the hydrogen ion concentration of a solution; a measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is neutral.

Phytoplankton algae— Free-floating, mostly microscopic aquatic plants.

Chlorophyll-*a (chl-a)* — Primary light-trapping pigment in most phytoplankton algae. Concentration can be used as an indirect indicator of the abundance of phytoplankton algae in a lake or other water body.

Runoff— The part of precipitation that appears in surface streams. It is equivalent to streamflow unaffected by artificial diversions, storage, or other human works in or on the stream channel.

Secondary maximum contaminant level (SMCL) — Maximum recommended level of a contaminant in water that is delivered to any user of a public water system. These contaminants affect the esthetic quality of the water such as odor or appearance; therefore, the levels are intended as guidelines. *See also* Maximum contaminant level.

Specific conductance — A measure of the ability of a sample of water to conduct electricity normalized to 25°C.

Subbasin — Drainage basin or watershed defined by a specific monitoring station and representing the land area that contributes water to that station.

Surface water — An open body of water, such as a stream or lake.

Thermal stratification — Seasonal division of a lake or other water body into a warm upper layer and a cold deep layer that is no longer in contact with the atmosphere. In some lakes, thermal stratification can result in a loss of oxygen in the deep layer and subsequent chemical stratification.

Trihalomethane formation potential (THMFP) — Tendency of naturally occurring organic compounds in a water supply to form toxic trihalomethanes during water treatment.

Trophic state — The extent to which a body of water is enriched with plant nutrients. *See also* Eutrophic, Mesotrophic, Oligotrophic.

Trophic state index (TSI) — A numerical index indicating the degree of nutrient enrichment of a body of water.

Turbidity — The opaqueness or reduced clarity of a fluid due to the presence of suspended matter.

Water year — The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with the surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1998, is referred to as the "1998" water year. This report, however, operates on a calendar year.

Wetlands — Lands that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Yield — The weight of material transported during any given time divided by unit drainage area, such as kilograms per day per square kilometer or tons per year per square mile.

15 Appendix A: CWD Site Names and USGS Codes

Table 37. CWD site names and corresponding USGS station numbers

CWD ID	USGS Station Number
HB @ MILL ST	01104405
SALT DEPOT	01104410
LEX BROOK	01104415
TRACER LN	01104420
HB BELOW DAM	01104430
INDUST BROOK	01104433
SB @ VILES	01104370
HB @ KG	01104440
MBS	01104453
WA-17	01104455
RT 20	01104460
SUMMER ST	01104475
STONY BROOK DAM	01104480

16 Appendix B: Quality Control Results

16.1 Field Duplicate Results

The precision of samples and corresponding field duplicates was measured using the Relative Percent Difference (RPD) metric. RPD was calculated using the equation:

$$RPD = \frac{|x_1 - x_2|}{(x_1 + x_2) * (\frac{1}{2})} * 100\%$$

x_1 and x_2 are the CWD measurement and corresponding field duplicate measurement

Due to the nature of measurement error and environmental sampling constraints, differences within 20 percent are generally considered acceptable measurements. The average RPD for all duplicate samples analyzed by the CWD laboratory and presented in this report was 11 percent (Table 38).[15] The average RPD for parameters analyzed by a contract laboratory, Microbac Laboratories, Inc., was 16 percent. While certain individual tests had an RPD above 20 percent, on average the RPD between duplicate samples was below 20 percent (Table 38 and Table 39). Ammonia, *E. coli*, and total coliform had the greatest rate of RPDs greater than 20 percent. Large variations between samples and duplicates could represent environmental variation, contamination of the sample, or an error in the laboratory analysis.

Table 38: Field duplicate relative percent difference (RPD) summary statistics for all parameters, 2018

RPD	Microbac	CWD – reported parameters	CWD – all parameters
Average	16%	11%	12%
Min	0%	0%	0%
Max	77%	133%	188%
See footnote 15 regarding sites included in the average RPD calculations. "CWD - reported parameters" statistics were calculated using only parameters discussed in this report. "CWD – all parameters" includes the RPDs for all parameters analyzed by CWD in 2018.			

[15] This average includes RPDs for duplicate samples collected at Blacks Nook and Little Fresh Pond. These sites are two small ponds located at Fresh Pond Reservation and are sampled by CWD on a quarterly basis. The ponds are not part of the drinking water supply, so water quality results from these stations are not discussed in this report. However, the results of duplicate samples collected at these locations are reported in Table 39. Go to https://www.cambridgema.gov/Water/watershedmanagementdivision/sourcewaterprotectionprogram/sourcewaterqualitymonitoringprogram/datamanagement/reportsandresearch to view water quality reports specific to these ponds.

Table 39: Field Duplicate (FDUP) Relative Percent Difference (RPD) Results, 2018

Site Name	Date	Parameter	Sample Result	FDUP Result	RPD (%)	Parameter	Sample Result	FDUP Result	RPD (%)
LFP									
	2/21/2018								
		NH3 (mg/L)	0.087	0.130	40%	E. coli (MPN/100 ml)	3	2	40%
		TKN (mg/L)	0.625	0.548	13%	Fe (mg/L)	0.590	0.190	103%
		TP (mg/L)	0.027	0.030	11%	Mn (mg/L)	0.227	0.094	83%
		NO3 (mg/L)	0.050	0.050	0%	Lab pH	7.04	7.05	0%
		NO2 (mg/L)	0.010	0.010	0%	Na (mg/L)	53	99	61%
		Chl-a (mg/m3)	15.0	14.4	4%	SO4 (mg/L)	6.8	6.8	0%
		Al (mg/L)	0.024	0.033	32%	Total Alkalinity (mg CaCO3/L)	43	43.5	1%
		Ca (mg/L)	21	26	18%	Total Coliform (MPN/100ml)	4	2	67%
		Cl (mg/L)	97	93	4%	TOC (mg/L)	4.5	4.9	9%
		Color (CU)	26	26	0%	Turbidity (NTU)	2.8	2.7	4%
		Conductivity (uS/cm)	390	394	1%	UV254 (abs)	0.125	0.120	4%
HB@MillSt									
	4/10/2018								
		NH3 (mg/L)	0.072	0.162	77%	E. coli (MPN/100 ml)	22	19	15%
		TKN (mg/L)	0.411	0.491	18%	Fe (mg/L)	0.180	0.330	59%
		TP (mg/L)	0.015	0.018	19%	Mn (mg/L)	0.028	0.029	4%
		NO3 (mg/L)	0.252	0.250	1%	Lab pH	6.45	6.61	2%
		NO2 (mg/L)	0.005	0.005	0%	Na (mg/L)	61	61	0%
		Chl-a (mg/m3)				SO4 (mg/L)	10.8	10.8	0%
		Al (mg/L)	0.134	0.121	10%	Total Alkalinity (mg CaCO3/L)	14	13.5	4%
		Ca (mg/L)	15	15	0%	Total Coliform (MPN/100ml)	118	517	126%
		Cl (mg/L)	102	103	1%	TOC (mg/L)	8.0	7.9	1%
		Color (CU)	63	65	3%	Turbidity (NTU)	1.1	1.3	14%
		Conductivity (uS/cm)	382	389	2%	UV254 (abs)	0.411	0.406	1%

Table 39: Field Duplicate (FDUP) Relative Percent Difference (RPD) Results, 2018

Site Name	Date	Sample Result	FDUP Result	RPD (%)		Sample Result	FDUP Result	RPD (%)
HB@Middle								
	5/15/2018							
NH3 (mg/L)		0.140	0.111	23%	E. coli (MPN/100 ml)	1	5	133%
TKN (mg/L)		0.594	0.640	7%	Fe (mg/L)	0.660	0.620	6%
TP (mg/L)		0.028	0.031	11%	Mn (mg/L)	0.161	0.150	7%
NO3 (mg/L)		0.096	0.094	2%	Lab pH	6.68	6.77	1%
NO2 (mg/L)		0.005	0.005	0%	Na (mg/L)	138	140	1%
Chl-a (mg/m3)		2.7			SO4 (mg/L)	9.2	9.2	0%
Al (mg/L)		0.090	0.090	0%	Total Alkalinity (mg CaCO3/L)	23	23.5	2%
Ca (mg/L)		24	25	3%	Total Coliform (MPN/100ml)	3	99	188%
Cl (mg/L)		214	214	0%	TOC (mg/L)	6.6	6.6	0%
Color (CU)		59	59	0%	Turbidity (NTU)	1.7	1.8	1%
Conductivity (uS/cm)		732	736	1%	UV254 (abs)	0.372	0.369	1%
FP@DH								
	7/3/2018							
NH3 (mg/L)		0.069	0.101	38%	E. coli (MPN/100 ml)			
TKN (mg/L)		0.369	0.371	1%	Fe (mg/L)	0.200	0.190	5%
TP (mg/L)		0.012	0.011	10%	Mn (mg/L)	0.034	0.032	6%
NO3 (mg/L)		0.582	0.567	3%	Lab pH	7.50	7.52	0%
NO2 (mg/L)		0.010	0.015	38%	Na (mg/L)	131	118	10%
Chl-a (mg/m3)		2.0	2.0	0%	SO4 (mg/L)	14.6	14.5	1%
Al (mg/L)		0.020	0.020	0%	Total Alkalinity (mg CaCO3/L)	28	26.5	6%
Ca (mg/L)		33	29	13%	Total Coliform (MPN/100ml)			
Cl (mg/L)		212	212	0%	TOC (mg/L)	3.8	3.8	0%
Color (CU)		13	13	0%	Turbidity (NTU)	0.4	0.5	7%
Conductivity (uS/cm)		744	749	1%	UV254 (abs)	0.122	0.122	0%

Table 39: Field Duplicate (FDUP) Relative Percent Difference (RPD) Results, 2018

Site Name	Date	Sample Result	FDUP Result	RPD (%)		Sample Result	FDUP Result	RPD (%)
FP@Intake								
	7/3/2018							
NH3 (mg/L)					E. coli (MPN/100 ml)	4	8	67%
TKN (mg/L)					Fe (mg/L)			
TP (mg/L)					Mn (mg/L)			
NO3 (mg/L)					Lab pH			
NO2 (mg/L)					Na (mg/L)			
Chl-a (mg/m3)					SO4 (mg/L)			
Al (mg/L)					Total Alkalinity (mg CaCO3/L)			
Ca (mg/L)					Total Coliform (MPN/100ml)	214	210	2%
Cl (mg/L)					TOC (mg/L)			
Color (CU)					Turbidity (NTU)			
Conductivity (uS/cm)					UV254 (abs)			
SB@DH								
	9/25/2018							
NH3 (mg/L)		0.112	0.071	45%	E. coli (MPN/100 ml)			
TKN (mg/L)		0.486	0.652	29%	Fe (mg/L)	0.280	0.230	20%
TP (mg/L)		0.014	0.012	16%	Mn (mg/L)	0.308	0.284	8%
NO3 (mg/L)		0.187	0.190	2%	Lab pH	7.20	7.18	0%
NO2 (mg/L)		0.019	0.018	7%	Na (mg/L)	127	120	6%
Chl-a (mg/m3)		2.4	2.5	5%	SO4 (mg/L)	10.0	10	0%
Al (mg/L)		0.010	0.010	0%	Total Alkalinity (mg CaCO3/L)	31	26.5	16%
Ca (mg/L)		28	27	4%	Total Coliform (MPN/100ml)			
Cl (mg/L)		222	221	0%	TOC (mg/L)	4.6	4.7	2%
Color (CU)		24	25	4%	Turbidity (NTU)	1.2	1.2	0%
Conductivity (uS/cm)		796	803	1%	UV254 (abs)	0.174	0.174	0%

Table 39: Field Duplicate (FDUP) Relative Percent Difference (RPD) Results, 2018

SB@Intake — 9/25/2018

Site Name	Date	Sample Result	FDUP Result	RPD (%)		Sample Result	FDUP Result	RPD (%)
NH3 (mg/L)					E. coli (MPN/100 ml)	12	12	0%
TKN (mg/L)					Fe (mg/L)			
TP (mg/L)					Mn (mg/L)			
NO3 (mg/L)					Lab pH			
NO2 (mg/L)					Na (mg/L)			
Chl-a (mg/m3)					SO4 (mg/L)			
Al (mg/L)					Total Alkalinity (mg CaCO3/L)			
Ca (mg/L)					Total Coliform (MPN/100ml)	1120	816	31%
Cl (mg/L)					TOC (mg/L)			
Color (CU)					Turbidity (NTU)			
Conductivity (uS/cm)					UV254 (abs)			

TracerLn — 10/18/2018

Site Name	Date	Sample Result	FDUP Result	RPD (%)		Sample Result	FDUP Result	RPD (%)
NH3 (mg/L)		0.151	0.160	6%	E. coli (MPN/100 ml)	51	56	9%
TKN (mg/L)		0.572	0.554	3%	Fe (mg/L)	1.150	1.190	3%
TP (mg/L)		0.044	0.074	52%	Mn (mg/L)	0.269	0.269	0%
NO3 (mg/L)		0.587	0.464	23%	Lab pH	6.63	6.66	0%
NO2 (mg/L)		0.005	0.005	0%	Na (mg/L)	178	189	6%
Chl-a (mg/m3)					SO4 (mg/L)	7.6	7.3	4%
Al (mg/L)		0.030	0.030	0%	Total Alkalinity (mg CaCO3/L)	57	55	3%
Ca (mg/L)		42	44	4%	Total Coliform (MPN/100ml)	2420	2419.6	0%
Cl (mg/L)		277	278	0%	TOC (mg/L)	4.5	4.7	4%
Color (CU)		43	44	2%	Turbidity (NTU)	2.6	2.8	6%
Conductivity (uS/cm)		1140	1130	1%	UV254 (abs)	0.313	0.298	5%

Table 39: Field Duplicate (FDUP) Relative Percent Difference (RPD) Results, 2018

Site Name	Date	Sample Result	FDUP Result	RPD (%)		Sample Result	FDUP Result	RPD (%)
BlacksNook								
	12/4/2018							
NH3 (mg/L)		0.086	0.122	35%	E. coli (MPN/100 ml)	63	47	29%
TKN (mg/L)		0.494	0.526	6%	Fe (mg/L)	0.280	0.260	7%
TP (mg/L)		0.031	0.029	7%	Mn (mg/L)	0.039	0.041	5%
NO3 (mg/L)		0.050	0.050	0%	Lab pH	7.36	7.27	1%
NO2 (mg/L)		0.010	0.010	0%	Na (mg/L)	9	10	11%
Chl-a (mg/m3)		20.0			SO4 (mg/L)	0.1	0.2	67%
Al (mg/L)		0.010	0.010	0%	Total Alkalinity (mg CaCO3/L)	45	46.5	3%
Ca (mg/L)		14	15	3%	Total Coliform (MPN/100ml)	411	192	73%
Cl (mg/L)		18	18	1%	TOC (mg/L)	5.0	5.2	4%
Color (CU)		19	19	0%	Turbidity (NTU)	1.7	1.8	2%
Conductivity (uS/cm)		144	142	1%	UV254 (abs)	0.120	0.121	1%
MBS								
	12/13/2018							
NH3 (mg/L)		0.173	0.215	22%	E. coli (MPN/100 ml)	1	1	0%
TKN (mg/L)		0.527	0.602	13%	Fe (mg/L)	0.310	0.350	12%
TP (mg/L)		0.012	0.014	16%	Mn (mg/L)	0.026	0.030	14%
NO3 (mg/L)		1.250	1.260	1%	Lab pH	6.58	6.56	0%
NO2 (mg/L)		0.021	0.023	7%	Na (mg/L)	85	86	1%
Chl-a (mg/m3)					SO4 (mg/L)	14.6	14.4	1%
Al (mg/L)		0.080	0.090	12%	Total Alkalinity (mg CaCO3/L)	27	26.5	0%
Ca (mg/L)		17	18	4%	Total Coliform (MPN/100ml)	261	65	120%
Cl (mg/L)		121	118	3%	TOC (mg/L)	7.9	7.9	0%
Color (CU)		59	59	0%	Turbidity (NTU)	0.8	0.8	1%
Conductivity (uS/cm)		507	504	1%	UV254 (abs)	0.391	0.391	0%

16.2 Field Blanks Results

Field blanks in 2018 were included with tributary and reservoir samples on March 20, April 11, July 20, June 13, July 5, October 10, November 8, December 5, and December 6 (Table 40). Nearly all results were below the detection limit or were not detected in quantities large enough to meaningfully affect sample results presented in this report. Values for pH were within the expected ranges for de-ionized water exposed to the atmosphere.

Table 40: Field Blank Results, 2018

Site Name	Date	Parameter	Qualifier	Field Blank Result	Parameter	Qualifier	Field Blank Result
TracerLn							
	3/20/2018						
		NH3 (mg/L)		0.059	E. coli (MPN/100 ml)	<	1
		TKN (mg/L)	<	0.100	Fe (mg/L)	<	0.010
		TP (mg/L)	<	0.011	Mn (mg/L)		0.000
		NO3 (mg/L)	<	0.005	Lab pH		6.17
		NO2 (mg/L)	<	0.005	Na (mg/L)		0
		Chl-a (mg/m3)			SO4 (mg/L)		1
		Al (mg/L)	<	0.000	Total Alkalinity (mg CaCO3/L)		2.5
		Ca (mg/L)		0	Total Coliform (MPN/100ml)		6
		Cl (mg/L)		0	TOC (mg/L)		0.2
		Color (CU)	<	1	Turbidity (NTU)		0.1
		Conductivity (uS/cm)		30	UV254 (abs)		0.001
SB@DH							
	4/11/2018						
		NH3 (mg/L)	<	0.050	E. coli (MPN/100 ml)	<	1
		TKN (mg/L)	<	0.100	Fe (mg/L)		0.020
		TP (mg/L)	<	0.011	Mn (mg/L)		0.000
		NO3 (mg/L)	<	0.005	Lab pH		5.98
		NO2 (mg/L)	<	0.005	Na (mg/L)		0
		Chl-a (mg/m3)	<	2.0	SO4 (mg/L)		11.6
		Al (mg/L)	<	0.000	Total Alkalinity (mg CaCO3/L)		2
		Ca (mg/L)		0	Total Coliform (MPN/100ml)	<	1
		Cl (mg/L)		0	TOC (mg/L)		0.1
		Color (CU)	<	1	Turbidity (NTU)		0.1
		Conductivity (uS/cm)		1	UV254 (abs)		0.001

Table 40: Field Blank Results, 2018

Site Name	Date	Field Blank Result			Field Blank Result		
FP@DH							
	6/13/2018						
		NH3 (mg/L)	<	0.050	E. coli (MPN/100 ml)	<	1
		TKN (mg/L)	<	0.100	Fe (mg/L)	<	0.010
		TP (mg/L)	<	0.011	Mn (mg/L)		0.000
		NO3 (mg/L)	<	0.005	Lab pH		5.81
		NO2 (mg/L)	<	0.005	Na (mg/L)		0
		Chl-a (mg/m3)			SO4 (mg/L)		0
		Al (mg/L)		0.000	Total Alkalinity (mg CaCO3/L)		2.5
		Ca (mg/L)		0	Total Coliform (MPN/100ml)	<	1
		Cl (mg/L)		0	TOC (mg/L)		0.2
		Color (CU)	<	1	Turbidity (NTU)		0.1
		Conductivity (uS/cm)		1	UV254 (abs)		0.005
HB@Upper							
	7/5/2018						
		NH3 (mg/L)		0.106	E. coli (MPN/100 ml)	<	1
		TKN (mg/L)	<	0.100	Fe (mg/L)	<	0.010
		TP (mg/L)	<	0.011	Mn (mg/L)		0.000
		NO3 (mg/L)	<	0.050	Lab pH		5.78
		NO2 (mg/L)	<	0.010	Na (mg/L)		0
		Chl-a (mg/m3)	<	2.0	SO4 (mg/L)		0.8
		Al (mg/L)		0.000	Total Alkalinity (mg CaCO3/L)		2
		Ca (mg/L)		0	Total Coliform (MPN/100ml)	<	1
		Cl (mg/L)		0	TOC (mg/L)		0.4
		Color (CU)	<	1	Turbidity (NTU)		0.2
		Conductivity (uS/cm)		2	UV254 (abs)		0.001

Table 40: Field Blank Results, 2018

Site Name	Date	Field Blank Result			Field Blank Result	
LexBrook	10/10/2018					

Parameter		Field Blank Result	Parameter		Field Blank Result
NH3 (mg/L)	<	0.050	E. coli (MPN/100 ml)	<	1
TKN (mg/L)	<	0.100	Fe (mg/L)	<	0.010
TP (mg/L)	<	0.011	Mn (mg/L)		0.000
NO3 (mg/L)	<	0.005	Lab pH		5.78
NO2 (mg/L)	<	0.005	Na (mg/L)		0
Chl-a (mg/m3)			SO4 (mg/L)		0
Al (mg/L)		0.000	Total Alkalinity (mg CaCO3/L)		2
Ca (mg/L)		0	Total Coliform (MPN/100ml)	<	1
Cl (mg/L)		0	TOC (mg/L)		0.4
Color (CU)	<	1	Turbidity (NTU)		0.1
Conductivity (uS/cm)		3	UV254 (abs)		0.001

Site Name	Date
FP@Intake	11/8/2018

Parameter		Field Blank Result	Parameter		Field Blank Result
NH3 (mg/L)			E. coli (MPN/100 ml)	<	1
TKN (mg/L)			Fe (mg/L)		
TP (mg/L)			Mn (mg/L)		
NO3 (mg/L)			Lab pH		
NO2 (mg/L)			Na (mg/L)		
Chl-a (mg/m3)			SO4 (mg/L)		
Al (mg/L)			Total Alkalinity (mg CaCO3/L)		
Ca (mg/L)			Total Coliform (MPN/100ml)	<	1
Cl (mg/L)			TOC (mg/L)		
Color (CU)			Turbidity (NTU)		
Conductivity (uS/cm)			UV254 (abs)		

Table 40: Field Blank Results, 2018

Site Name	Date		Field Blank Result			Field Blank Result
HB@Upper						
	12/5/2018					
NH3 (mg/L)			0.058	E. coli (MPN/100 ml)	<	1
TKN (mg/L)		<	0.100	Fe (mg/L)	<	0.010
TP (mg/L)		<	0.011	Mn (mg/L)		0.000
NO3 (mg/L)		<	0.050	Lab pH		5.36
NO2 (mg/L)		<	0.010	Na (mg/L)		0
Chl-a (mg/m3)		<	2.0	SO4 (mg/L)		0
Al (mg/L)			0.000	Total Alkalinity (mg CaCO3/L)		2
Ca (mg/L)			0	Total Coliform (MPN/100ml)	<	1
Cl (mg/L)			0	TOC (mg/L)		0.3
Color (CU)		<	1	Turbidity (NTU)		0.1
Conductivity (uS/cm)			1	UV254 (abs)		0.011

Site Name	Date		Field Blank Result			Field Blank Result
HBBelowDam						
	12/6/2018					
NH3 (mg/L)		<	0.050	E. coli (MPN/100 ml)	<	1
TKN (mg/L)		<	0.100	Fe (mg/L)	<	0.010
TP (mg/L)		<	0.011	Mn (mg/L)		0.000
NO3 (mg/L)		<	0.050	Lab pH		5.66
NO2 (mg/L)		<	0.010	Na (mg/L)		0
Chl-a (mg/m3)				SO4 (mg/L)		0
Al (mg/L)			0.000	Total Alkalinity (mg CaCO3/L)		2
Ca (mg/L)			0	Total Coliform (MPN/100ml)	<	1
Cl (mg/L)			0	TOC (mg/L)		0.3
Color (CU)			1	Turbidity (NTU)		0.1
Conductivity (uS/cm)			3	UV254 (abs)		0.001

17 Appendix C: Load and Yield Calculations

17.1 Load and Yield Calculations

Annual base-flow load and yield of sodium, chloride, nitrate and nitrite nitrogen, and TP were calculated at each monitoring station as follows:

$Load_{base\text{-}flow} = \mu_{CWD} \times Q_{base\text{-}flow}$

$Yield_{base\text{-}flow} = Load_{base\text{-}flow}$ / tributary catchment area

Where:

μ_{CWD} = 2018 mean concentration of sodium, chloride, nitrate and nitrite nitrogen, TN, or TP measured by CWD during dry conditions, in mg/L

$Q_{base\text{-}flow}$ = 2018 base-flow, in L/yr

In 2018, the USGS collected sodium, chloride, and TP stormwater water quality samples from Lex Brook (01104415), Tracer Lane (01104420), WA-17 (01104455), and Summer St (01104475). This allowed CWD to calculate stormwater loads and yields for these parameters using the same process as above except using stormwater volumes and mean concentrations.

17.2 Stormflow and Base-flow Separation of Continuous Discharge Data

The volume of base-flow ($Q_{base\text{-}flow}$) and stormflow ($Q_{storm\text{-}flow}$) at tributary sites with continuous discharge data was calculated using the Fixed-Interval Method for base-flow and stormflow separation (Sloto and Crouse, 1996). In 2018, continuous USGS discharge data were available from the USGS National Water Information System website for the following stations: Lex Brook (01104415), Tracer Lane (01104420), HB Below Dam (01104430), SB @ Viles (01104370), WA-17 (01104455), Summer St (01104475), and RT 20 (01104460). The USGS also maintained a continuous water level logger at Salt Depot (01104410) after discontinuing discharge monitoring in 2016. CWD maintained the USGS-provided stage-discharge relationship in 2018 by conducting periodic discharge measurements and applying gage height adjustments and rating curve shifts as needed, allowing for the calculation of continuous discharge data.[16] Continuous discharge data were also available at HB @ KG from a CWD-maintained water level logger and rating curve.

With the Fixed Interval Method, the lowest recorded discharge value over a fixed time interval (3 to 11 days) is used to represent base-flow over the entire interval (Sloto and Crouse, 1996). The fixed time

[16] From December 26, 2017 through January 12, 2018, the Salt Depot water level started drifting upward and became unrealistically high. During the same period, gage heights recorded by the USGS sensors at Lex Brook and Summer St stayed stable or trended down. Because water level patterns at Salt Depot did not correspond to precipitation patterns or gage height patterns at Lex Brook and Summer St, Salt Depot discharge data were estimated during this time period by downscaling USGS approved instantaneous discharge from Summer St based on relative catchment area size as described by the Ohio Environmental Protection Agency (2009).

interval (2N*) is a function of the drainage area of a catchment, and is calculated by first estimating the recession period for surface runoff following a storm event:

$N=A^{0.2}$

Where:

N=recession period, A=area of catchment (sq. mi)

2N* = the odd integer between 3 and 11 closest to twice the recession period (N*2)

In this study, all catchments had intervals of 3 days. Therefore, base-flow was calculated as the lowest discharge value in each three-day period of 2018. For example, base-flow for each day between January 1 and January 3 was assigned based on the minimum value recorded during the interval. The same process was repeated for the next three days, January 4 – January 6. Stormflow was calculated as the difference between total discharge and base-flow.[17] A difference of zero between total discharge and base-flow represents dry conditions with no stormflow.

Annual total discharge, base-flow, and stormflow were calculated by integrating the discharge data for each category[18]:

$$Q_{annual} = ((Q_2+Q_1)/2)*(t_2-t_1) + ((Q_3+Q_2)/2)*(t_3-t_2)...+ ((Q_n+Q_{n-1})/2)*(t_n-t_{n-1})$$

Where:

Q_{annual} = annual total discharge, base-flow, or stormflow in cubic feet per year

Q_n = instantaneous total discharge, base-flow, or stormflow in cubic feet per second

t_n = time and date of instantaneous discharge reading, in seconds elapsed since 1/1/1970[19]

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[17] Discharge at RT 20 and HB @ KG is heavily influenced by upstream releases of water from the Hobbs Brook Reservoir. Increases in discharge can be attributable to both storm events and managed releases of water from the reservoir. To avoid erroneously counting dam releases as stormflow, the daily average discharge measured from the HB Below Dam gage was subtracted from the daily average discharge at RT 20 and HB @ KG. Base-flow at these sites was then calculated as the three-day minimum of these differences. For the purposes of calculating loads and yields, water released from Hobbs Brook Reservoir was treated as base-flow. Therefore, after calculating daily base-flow, the daily mean discharge from the HB Below Dam was added to the mean daily base-flow rate for each site. Daily stormflow at each site was calculated by subtracting the sum of the daily base-flow and daily HB Below Dam flow from total mean daily flow.

[18] Daily mean discharge data in cfs were used to calculate stormflow and base-flow at RT 20 and HB @ KG as described in the previous footnote. Rather than integrate the daily data, mean daily discharge in cfs was converted into cubic feet per day by multiplying by 86,400 (the number of seconds in a day) and summed to calculate the total cubic feet of water per year.

[19] In R, dates and times in POSIXct format record the data as the number of seconds elapsed since January 1, 1970. All stormflow and base-flow separation and load and yield calculations were performed in the R programing platform.

17.3 Instantaneous Base-flow Volume Calculation

For sites without continuous discharge data (HB @ Mill St, Indust Brook, and MBS), CWD performed discrete discharge measurements in cubic feet per second (cfs) during each base-flow water quality sampling event. These measurements were averaged to estimate the average annual base-flow in cfs. The total annual base-flow ($Q_{base\text{-}flow}$, in L/yr) was calculated by multiplying this average (cfs) by the number of seconds in a year (31,536,000 seconds) to derive total cubic feet of flow. This total was then converted from cubic feet to liters.